INNOVATION DIFFUSION WITHIN THE UK CONSTRUCTION SECTOR: A STUDY OF THE ADOPTION OF 4D BIM

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ABSTRACT

The construction industry suffers from a time predictability problem. To address this, previous research has investigated various improvement strategies, including the exploitation of innovations. An innovation is some ‘thing’, unfamiliar to an entity, which can facilitate product, process or systemic improvements. Innovation diffusion theory (IDT) is the body of work concerned with explaining how some innovations successfully ‘stick’, whilst others fail to propagate. These phenomena occur across society, but construction is particularly perceived to suffer from a low ‘innovation rate’. 4D BIM is an innovation with potential to provide construction planning improvements that can address the time predictability problem, but there are concerns around its prospective industry absorption. This research investigates the applicability of classic IDT to the adoption of 4D BIM by the UK construction industry. A mixed-method study was undertaken, informed by a pragmatist philosophy. It combines an initial exploratory stage that uses case study and questionnaire survey research, with a subsequent explanatory stage concurrently employing a second questionnaire survey with semi-structured interviews. Classified as a modular technical process-based innovation, use of 4D BIM is found to advance construction planning. It increases feedback opportunities, planning efforts, and the quality and validity of the plans produced, whilst also having potential for improving project time performance. It is established that 4D BIM usage is principally limited to work-winning, methods planning, and the visualisation of construction processes, alleviating problems of communication and understanding. The importance of existing diffusion concepts of *compatibility* and *trialability*, are reinforced, and several new contributions are made. These include: how organisations using BIM risk employing hybrid project information delivery processes, resulting in duplication of effort and inefficiency; how personal use of 4D BIM is linked to organisational characteristics; and what the usual time lag between first awareness and adoption is. Furthermore, an existing innovation-decision process model is built upon, with additional stages, decision-action points and outcomes added. This new model can assist in the future adoption/rejection decisions of such modular technical process-based innovations.

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This work is dedicated to my beautiful wife Emma, without whom I truly would have nothing. At the start of this journey I was new to research, teaching, and to marriage. Toward the end of the research, I find that (largely) thanks to her, we have a wonderful young family. James arrived first, followed by George shortly afterwards. In this, she has blessed me.

Author's declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Any ethical clearance for the research presented in this thesis has been approved. Final approval was granted by the Faculty Ethics Committee on 27 May 2015.

I declare that the Word Count of this Thesis is 85,716 words

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Signature:

Date:

Chapter 1: Introduction

There is a serious problem of time predictability in the delivery of construction projects, and for many years' construction managers and construction management theorists have looked to a variety of technical and process based innovations as possible solutions. One such innovation is 4D BIM, which has the potential to provide improvements both in construction planning and in project time performance. Innovations however, do not always have their promised transformational effect. They may 'take off' more slowly than expected, or not at all. 'Innovation diffusion theory' (IDT) is a body of work that is concerned with explaining these phenomena and it is particularly relevant to the present study. This chapter provides a broad overview of the UK Construction industry and contains information regarding sectoral size, scale and structure. It lists the multitude of industry reviews that have identified global problems within the practice of construction management; and introduces the two key problems central to this study: the time predictability of construction projects, and problems with the diffusion of construction industry innovations. 4D BIM innovation is then identified as a possible solution to the time predictability problem and the applicability of innovation diffusion theory to the study is briefly introduced. The research aims and objectives are then provided and the distinctiveness of the study is identified. The chapter concludes by outlining the structure of the work and advising of the content of each chapter.

1.1 The UK Construction Industry

The construction sector is a major part of the UK economy. It represents between 6.5–8.0% of gross domestic product (GDP), approximately £110bn per annum of expenditure (HM Government 2011; 2016) and delivers around £69 billion gross value added (GVA) to the UK economy (HM Government 2012). The sector can be considered to include "*(i) construction contracting industry; (ii) provision of construction related professional services; and (iii) construction related products and materials*" (BIS, 2013). Employment across the industry was expected to be just below 2.6 million persons by 2016, and Myers (2013) approximate analysis of available data suggested 1,200,000 workers were employed in the traditional construction contracting, supplemented by 450,000 people who supply professional services, 650,000 building product/equipment manufacturing sector employees, 25,000 raw material mining/quarrying employees and 100,000 building material sales related employees. Additionally, construction is recognised and reported on by organisations such as the Office for National Statistics (ONS), the Department for Business Innovation and Skills (BIS) and the Construction Industry Council (CIC) as being the accepted and recognised term for the following economic sectors: Infrastructure (including civil engineering); Private and public housing; Public non-housing (education; healthcare etc); Industrial; and Commercial. This data is often further split across new work and repair and maintenance work, with approximately 40% of available work being in the public sector, making central Government the industry's largest client (HM Government 2011). Section F of the UK Standard Industrial Classification of Economic Activities (2007) categorises Construction as an umbrella term for further division of economic activity including the Construction of buildings; Civil engineering; and Specialised construction activities[1] (ONS, 2007). Researchers such as Ofori (1990) argue that there is no true definition of the construction industry. This view is formed in part, because of the difficulties involved in defining the '*typical project*', with many researchers relying upon explanations that identify the one-of-a-kind characteristics of projects, such as the use of temporary multi-organisations and the nature of site based production (Cherns and Bryant, 1984). Indeed, Ballard and Howell (1998a) note "*What we call 'construction'*

1 Divisions 41-43 respectively.

covers a spectrum ranging from slow, certain, and simple (stodgy) projects on one end to quick, uncertain, and complex (dynamic) projects on the other". Myers (2013), however argues against any *narrow definition* of the construction industry such as those confined to the site based activities of firm and instead advocates a broad definition that encompasses the entire life cycle of construction, including: *"design, production, use, facility management, demolition etc* [… which …] *should include the mining and quarrying of raw materials, the manufacture and sale of construction products and the related professional services such as those of architects, engineers and facility managers"*.

1.2 Sector concerns and strategies

Regardless of how it is defined, it is accepted that the construction sector often underperforms, particularly in the delivery of its projects (Love *et al*., 2011). Industry reviews regularly identify long-term concerns and there have been several movements to reform poor performance in the construction industry. Notable initiatives were communicated in Constructing the Team (Latham, 1994) and Rethinking Construction (Egan, 1998) and more recent agendas have focused on low carbon, value creation and the use of Building Information Modelling (BIM) in recent Government Construction Strategies (2011; 2016). Table 1.1 provides a timeline of prominent construction industry reports.

Table 1.1: Construction industry reports. Adapted from Cooke and Williams (2009).

Report	Title	Year
Simon Report	The Placing and Management of Building Contracts	1944
Emmerson Report	Survey of Problems Before the Construction Industries	1962
Banwell Report	The Placing and Management of Contracts for Building and Civil Engineering Work	1964
National Economic Development Office	Action on Banwell	1967
Tavistock Report	Interdependence and Uncertainty	1966
Latham 1	Interim Report – Trust and Money	1993
Latham 2	Final Report – Constructing the Team	1994
Levene Efficiency Scrutiny	Construction Procurement by Government	1995
Egan 1	Rethinking Construction	1998
National Audit Office	Modernising Construction	2001
Egan 2	Accelerating Change	2002
Fairclough	Rethinking Construction Innovation and Research: A review of government R&D policies and practices	2002
National Audit Office	Improving Public Services through better construction	2005
HM Government	Strategy for Sustainable Construction	2008
Wolstenholme	Never Waste a Good Crisis	2009
IGT	Low Carbon Construction	2010
BIM Industry Working Group	A report for the Government Construction Client Group	2011
The Cabinet Office	Government Construction Strategy	2011
Department for Business, Innovation and Skills	Building Information Modelling. Industrial strategy: government and industry in partnership	2012
Department for Business, Innovation and Skills	Construction 2025. Industrial Strategy: government and industry in partnership	2013
The Infrastructure and Projects Authority	Government Construction Strategy 2016-20	2016

These reviews include recurring industry criticisms to do with issues such as fragmentation, inefficiency and waste (Latham 1994; Egan 1998; 2002; Wolstenholme 2009). Furthermore, researchers have highlighted the varying ability of organisations to respond to, and capitalise on innovations (Larsen, 2005b; Reza Hosseini *et al*., 2015; Murphy, Perera and Heaney, 2015). Reviewing long term concerns of industry inefficiency, Egan (1998) highlighted lean processes and new technologies including 3D object orientated modelling as possible solutions to many of the industry's problems, and stressed the need for measurement of industry performance. Use of industry-standard Key Performance Indicators (KPI’s) officially commenced in 1999[2] and Cain (2003), stresses that any initiative will fail to have significant impact unless the industry commits to continual measurement of performance and then acts upon the results. Particularly relevant to this study, is the KPI of ‘time predictability’, with Egan (1998) originally targeted a 10% annual reduction in this area.

1.3 The construction time predictability problem

Such focus on the time predictability of UK construction projects remains. Recently, the construction sector strategy commonly referred to as ‘Construction 2025’ (HM Government, 2013), included in its ‘Vision for 2025’ requirements for 50% faster project delivery (as benchmarked against 2013 UK industry performance), and reductions in the overall time, from inception to completion, for new build and refurbished assets. Yet despite such aspirations, annual KPI data repeatedly confirms poor UK construction project time predictability and has not demonstrated any true sustained improvement in this area. For example, in 2012 (immediately prior to the release of the Construction 2025 strategy), only 34% of UK construction projects were being delivered on, or before their original planned project end date,

2 See Adamson and Pollington (2006)

with 42% of construction phases delivered on or before their original planned completion date (Gledson and Greenwood, 2014; Gledson, 2015). Whilst variability exists in the subsequent data recorded across all three measures of time predictability, it should be stressed that more than half of UK construction projects continue to exceed their agreed time schedules. Table 1.2 shows KPI data reported for measures of construction time predictability from years 2007 to 2016.

Table 1.2: Construction time predictability for years 2007–2016, percentage of projects and phases delivered on time or better. Table adapted from Constructing Excellence (2016)

KPI	2007	2008	2009	2010	2011	2012	2013/14	2015	2016
Predictability Time: Project	58	45	45	43	45	34	45	40	41
Predictability Time: Design	58	58	53	69	51	48	52	53	48
Predictability Time: Construction	65	58	59	57	60	42	67	48	55

In addition to poor time predictability of overall project phases, the performance of individual construction tasks or work packages is less than satisfactory. Ballard (2000a) first identified that the planned percentage complete (PPC) of construction activities was typically 50%. Dawood (2010) devised a means of calculating planning efficiency – and found a percentage reliability of around 55 per cent meaning that for only 55% of the time, there is zero variance in the planned start dates or planned finish dates of construction activities or work packages.

The Lean Construction Institute identifies a historic focus upon improving productivity within much construction management research, and that "*traditional project planning was unable to produce predictable workflow: only 54% of the assignments made by foremen to be completed in the week were actually* *completed*" (LCI, no date). Within construction planning literature, several different methods have been championed to address these problems, such as the use of probabilistic task duration calculation methods, the critical chain method, location-based planning methods, and the last planner system. Arguably, all of these should have readily translated to improvements in planning efficiency: however, poor time predictability remains a concern. There has been limited improvement in this area and research efforts focusing on better project delivery have largely being devoted to front end activities (such as procurement systems) or 'soft' issues of communication and relationships (Hughes, 2012). Kenley (2014, p489) argues that efforts to improve process and productivity should be the *"holy grail of construction research"*, yet he recognises that terms such as 'productivity' have different meanings to individual practitioners and researchers as dictated by their perspectives. He suggests that productivity research is usually considered singly at either industry-, project- or activity-levels, and to combat this, a more systemic view should be adopted.

1.4 Potential solutions: BIM and 4D BIM innovations

In '*The Impact of Building Information Modelling: Transforming Construction'*, Crotty, (2012) asserts that poor quality project information causes two 'first order' issues confronting the UK construction industry; those of poor predictability and poor profitability. Crotty describes the nature of construction documentation received for production purposes as *"shapeless masses of ambiguous, subjective information, largely lacking in systematic content"* (p26). Low-quality project information is thus considered to be a primary cause of poor construction time predictability. The government drive for all major construction projects to be working at "*fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016*" is seen as an important step in improving the quality of project information across the industry (HM Government, 2011, 2012). This is based on the belief that BIM is an innovation that can improve the overall design and construction processes for all stakeholders through improvements in collaboration, communication and even the very culture of the construction industry (Waly and Thabet, 2003; Li *et al*., 2009; Eastman *et al.,* 2011; Barlish and Sullivan 2012), as well as improving individual aspects of the process including the time performance of construction projects. BIM enables 4D methods, where the dimension of time is linked to the 3D model (x + y + z + t) to allow visualisation of the time and space relationships of construction activities (Liston *et al*., 2001; Heesom and Mahdjoubi 2002; Buchmann-Slorup and Andersson 2010). Literature considers 4D planning as a useful addition to project scheduling (Koo and Fischer, 2000) and that 4D BIM can be used to analyse the construction schedule to assess its implementation (Mahalingam, Kashyap, and Mahajan, 2010; Trebbe, Hartmann and Dorée, 2015) thus helping reduce scheduling errors through plan interrogation and validation.

Given the emphasis on the need for quicker delivery of construction projects, the continuing record of poor time predictability, and the government mandate for BIM implementation on all centrally procured construction projects, there is a need to focus on the potential of BIM to improve the inputs, process, and outputs in the planning of construction projects. Although it appears that 4D BIM is an innovation that can help improve construction project time predictability, problems have previously been identified with innovation adoption in construction (Winch, 1998; Larsen and Ballal, 2005) and there have been calls for more research into industry innovation diffusion efforts (Larsen and Ballal, 2005; Widén and Hansson, 2007; Harty, 2008).

1.5 Aim and objectives

This study makes use of classic innovation diffusion theory (IDT) which will be introduced in the next chapter. It is hypothesised that, if innovation diffusion theory can be used to help explain 4D BIM innovation adoption within UK construction planning practices, then such a study can also be used to further contribute to innovation diffusion theory. Consequently, the aim of this study is:

To investigate the applicability of classic innovation diffusion theory to the adoption of 4D BIM by the UK construction industry.

This study has the following objectives:

1. Examine classic innovation diffusion theory and its applicability to the construction industry.
2. Analyse the planning of construction projects within the context of poor industry time predictability.
3. Examine, through the collection of empirical data, the development of 4D BIM in the UK construction industry.
4. Investigate the diffusion of 4D BIM within UK construction planning practice. *Specifically, a series of sub-objectives*[3] *are required to 'explore' and 'explain':*
    - The construction planning functions that 4D BIM is principally being used for.
    - The extent of use of 4D BIM.
    - The innovativeness of members of this construction social system.
    - The rate of adoption of 4D BIM Innovation.
    - The consequences of 4D BIM.

3 The rationale for these sub-objectives is fully detailed in C2.1.3, but in short, they relate to established types of diffusion research.

5. Through a study of 4D BIM, develop a model that further informs innovation diffusion theory.

1.6 Distinctiveness of the research

The subject of BIM and its influence on the ongoing improvement of the construction process is one of the most prominent issues in construction. The construction delivery process has a long history of being criticised for not innovating and not delivering the type of process improvements which can be seen in other industries. There is evidence of the industry beginning to attempt to begin practical application of theory to address the delivery issues including the use of BIM and better visualisation practices. Whilst there is currently a maturing base of academic literature relating to BIM, little of this concerns the actual adoption of specific BIM-related innovations, such as 4D BIM. In doing so, this study not only fills that gap, but also contributes to the general understanding of innovation adoption in the UK construction industry.

1.7 Structure of the work

The thesis is structured as follows:

- **Chapter 2**, the literature review, addresses each of the two key problems identified above: problems with the diffusion of construction industry innovations, and construction's time predictability problem. It commences by examining classic innovation diffusion theory and its applicability to the construction industry (2.1), and then variously analyses construction planning within the context of poor industry time predictability (2.2), considers how Building Information Modelling impacts upon the quality of construction industry production information (2.3), and introduces 4D BIM as an innovation that can further assist the construction planning process whilst having the potential for improving time predictability (2.4).

- **Chapter 3** outlines the research philosophy and identifies the mixed method research approach that was used.
- **Chapters 4** and **5** details the mixed-method, two-stage exploratory research undertaken, presenting the results of a case study, followed by a questionnaire survey.
- **Chapter 6** introduces the main research stage, and makes explicit how the key independent variables from IDT were further integrated in the design of the research instruments for the explanatory stage of the study.
- **Chapters 7-9** present the results of the explanatory questionnaire survey and semi-structured interviews.
- **Chapter 10** provides a new model of the innovation-decision process.
- **Chapter 11** concludes the study by providing a summary of the major issues raised during the investigation, articulates how the research objectives were met, identifies the limitations of the study, suggests potential areas for future research, and provides several recommendations for practice.

Chapter 2: Literature Review

The introductory chapter provided an outline of the structure of the UK construction industry, and introduced the two key problems central to this study: the time predictability of construction projects, and problems with the diffusion of construction industry innovations. The literature review chapter addresses each of these problems and starts by satisfying **Research Objective 1** in examining classic innovation diffusion theory and its applicability to the construction industry. Subsequent sections of this chapter review literature associated with construction planning, BIM and 4D BIM to satisfy **Research Objective 2** by analysing the planning of construction projects within the context of poor industry time predictability.

2.1 Innovation

An innovation is defined as "*an idea, practice or object that is perceived as new by an individual or other unit of adoption*" (Rogers, 2003). An innovation offers non-trivial improvements in products, processes or systems and is unfamiliar to the company/institution developing or making use of it (Hosseini *et al*., 2015). Researchers note that an innovation is not an idea, but involves the successful exploitation, implementation and management of such ideas (or 'inventions') to create value through their practical and commercial benefits (Egbu, 2004; Park, Nepal and Dulaimi, 2004; Kastelle and Steen 2011). Innovation offers opportunities for company growth and profit (Steele and Murray, 2004; Reichstein, Salter and Gann, 2005). Construction innovations can bring about time and cost reductions, safety and quality improvements as well as increases in competitive advantage and market share (Gambatese and Hallowell, 2011b). Egbu (2004) however, argues that the innovation trajectory of an organisation is constrained by its current market position and core competencies, as both of these factors can limit specific innovation opportunities available to them.

Innovation can be classified as organisational, marketing, product or process based (OECD, 2015) and should be considered in terms of their ‘disruption’ to the system in which they are located. Systems can be categorised as ‘simple’, ‘complicated’ or ‘complex’ and each system has definable characteristics. Simple systems contain small numbers of parts that are easy to understand, are easy to model and have predictable outcomes. Complicated systems have a larger number of parts, are difficult to understand, difficult to model and have unpredictable outcomes. Finally, complex systems are those that have a very large number of parts, have uncontrollable dynamics, where different models will produce different results and because of this all possible outcomes are difficult to predict (Loosemore, 2014). Both construction projects (Baccarini, 1996; Williams, 1999; Bertleson, 2003), and the industry itself (Winch, 2003; Harty, 2005; Manu *et al.,* 2010), have been described as complex dynamic systems, and Dubois and Gadde (2002) explain that the construction industry typifies a loosely coupled system requiring ‘tighter’ couplings between elements in temporary individual projects, to work in combination with ‘looser’ couplings within the larger overall permanent network outside of individual project interactions. These researchers argue both types of couplings are necessary for dealing with the complexity of construction although this “*particular pattern of couplings favours productivity in projects, while innovation suffers*” (p629).

Frequent innovation in construction does not appear to occur. Slaughter (1998; 2000), conceptualises five separate innovation types, and advises of the impacts that innovations can have on surrounding systems: *incremental innovations* may offer minor improvements over existing practices with minimal impacts on a system; the consequences of a minor *architectural innovation* may mean a reshaping of many wider system constituents; whereas *modular innovations* may produce significant improvements but may not require alteration of other system level components; *system innovation* is the introduction and interaction of multiple complementary innovations; finally *radical innovation* is a completely new approach meaning a redesign of the entire system is necessary. Slaughter concludes that the implementation of each distinct type of innovation necessitates varying levels of management input and commitment. Researchers (Koskela and Vrijhoef, 2001; Reichstein, Salter and Gann, 2005) argue that the most frequent innovations in construction are incremental or modular in nature, and are usually product-based generated by suppliers, because of difficulties in implementing architectural or radical innovations that require larger scale systematic change. Taylor and Levitt (2004a; 2004b) add that the rate of incremental product-based innovations in the Architecture, Engineering, and Construction (AEC) industries is no worse than the comparable manufacturing industry. However, because of the structural complexity of project-based industries, systemic process-based innovations that need to cross organisational boundaries diffuse at a slower rate.

In terms of innovation, the construction industry is deemed to be an under-performing sector in relation to its economic scale (Miozzo and Dewick, 2004; Widén and Hansson, 2007). In comparison with other industries, it is considered that, because of structural factors and the particularities of construction, it suffers from lower levels of 'direct' innovation than other 'comparable' industries (Slaughter, 1988; Koskela and Vrijhoef 2001; Demian and Walters, 2014). Any innovations that do occur, suffer from an associated problem of capturing innovation knowledge, as this is typically retained within individuals rather than organisations (Gann and Salter, 2000; Dave and Koskela, 2009; Emmitt and Ruikar, 2013) and is something that is symptomatic of the short-term project based nature of the industry.

Reichstein, Salter and Gann (2005) identify six unique ‘liabilities’ that limit the sectors capacity to innovate, these include liabilities of: projects; immobility; uncertainty in demand; smallness; separation and assembly. In contrast, Winch (1998, p269) argues that the industry is an active source of fresh thinking and innovation, but it is just the “*rate of innovation* [that] *lags behind most other sectors*”, and cites Gann *et al* (1992) when stating, *“innovation efforts in the industry are disproportionately orientated towards product-enhancement rather than process-improvement”*. In making the case for radical process-based innovation, Koskela and Vrijhoef (2001) state that construction innovation is hampered by the traditional transformation model of production being the prevalent theoretical model of construction. They explain that the uniqueness of construction along with its structural and institutional problems, are a *“primary hindrance for innovation”,* citing these as reasons why radical managerial innovations such as mass production (industrialised building) and lean production have not been successfully transferred from manufacturing to construction. They also argue that the *advancement of construction innovation requires a new, explicit and valid theory of construction* [to be] *created”.*

Koskela and Vrijhoef (2001) also argue that construction innovations efforts need to be understood within the context of the industry itself. Walker (2016, pp114-115) acknowledges that “*effective innovation requires an understanding of the context in which the innovation came about, the way that it may be adapted or* *replicated in future and the implications of this on creating value for an enterprise or organization*". This was also highlighted variously by Winch (2003) and Harty (2005), who explain that construction is a 'complex system industry' which is 'decentralised' but is characterised instead by the centrality of projects and their communication networks. It is the collaborations between temporary alliances of supply firms[1] and the balance of power distributions between the actors within these inter-organisational relationships that are of principle importance, when considering the rate of direct innovation. From this perspective, researchers (Winch, 1998; Slaughter, 2003; Miozzo and Dewick, 2004; Loosemore, 2014) consider that much invisible, incremental innovation occurs because of problem solving on projects, even when multiple inter-dependent companies work as part of a temporary project organisation (TPO's). Koskela and Vrijhoef (2001) however, warn that this problem solving only becomes innovation when the solutions found are retained as shared learning that can be reapplied to future projects, and because of the uniqueness of construction projects this can be difficult. Gann and Salter (2000, p961) acknowledge that projects are non-routine and that *"management of innovation is complicated by the discontinuous nature of project-based production in which, often, there are broken learning and feedback loops"*.

A further concern is that traditional measures of innovation also appear misleading when considering the currency of construction innovation. Several researchers (Winch, 2003; Reichstein, Salter, and Gann, 2005; Loosemore, 2014) make reference on how the use of Standard Industry Classifications (SIC) includes aspects of manufacturing, distribution and installation activities, but specifically excludes design where much of the product and process value

1Who Gann and Salter (2000) refer to as project-based, service-enhanced firms.

adding activity occurs within construction. Data is collected using a set method established within the Organisation for Economic Co-operation and Development (OECD), ‘Oslo Manual’ in order to make cross-national, cross-industry sectorial comparisons on innovation largely measured via expenditure on traditional research and development (R&D) business department units. This is a measure, that leads to the conclusion that the high turnover, low profit construction sector must consequently have lower levels of innovation. These researchers argue that these figures, along with other conventional data, such as the number of patents registered, are misleading, inaccurate and do not accurately capture realities of innovation within the construction sector. Loosemore (2014) highlights that the relationship between actual expenditure, and predicted increases in business productivity, growth and profit is disputed within the literature, as whilst some studies do show a positive connection, other studies show no connection, or even negative connections between the two. Ultimately, Loosemore (2014, citing Gann, 2000) makes clear that *“it is much more likely that innovation will continue to take place ‘around’ the construction industry rather than ‘within’ it, meaning that the absorptive capacity of firms to adopt new ideas will be the critical factor in driving innovation in the sector”.*

The introduction of Building Information Modelling (BIM) within construction, has been very visible, and the UK Government BIM mandate (HM Government, 2011) arrived during economic recession when strategic, organisational decisions of the timing of BIM implementation were influenced by unfavourable prevailing market considerations. Succar (2009, p357) identified its impact thus, *“Building Information Modelling (BIM) is an emerging technological and procedural shift within the Architecture, Engineering, Construction and Operations (AECO) industry”*. BIM has been classified both as an innovation (Brewer and Gajendran, 2012; Davies and Harty, 2013a) and a disruptive technology (Succar, Sher and Williams, 2012; Kassem *et al.,* 2014). Loosemore (2014) identifies that a disruptive innovation is defined by *"the extent to which it departs from industry norms … renders existing business models obsolete, changes the basis of competition in an industry and produces sustainable competitive advantage by changing the way a whole industry works"*. Poirier, Staub-French, and Forgues (2015, p46) believe BIM is such an innovation when noting "*BIM is seen by many as being a disruptive innovation, which is bringing about the reconfiguration of practices in the AEC industry*". Gledson (2016, p230) concurred, identifying that *"the most prominent radical, transformative and disruptive innovation to hit construction industry is the use of Building Information Modelling"*. The UK government mandate for all major construction projects to be working at BIM Level 2 by 2016 (HM Government, 2011) was seen as an important step in improving project time and cost predictability. BIM and 4D BIM can be contextualised as relatively new innovations at various industry, organisation, project and practitioner levels. It is predicted that the diffusion of 4D BIM innovation will result in improvements in the time predictability of construction projects through improvements to the construction planning process. Before these innovations can be more fully presented, it is necessary to first identify problems of construction innovation diffusion, then fully introduce innovation diffusion theory (IDT).

2.1.1 Innovation Diffusion

A systematic review of innovation diffusion literature undertaken by Hosseini *et al*., (2015) identified additional attributes of construction innovations as: forecasting process related benefits; generating value to organisational strategic outcomes; and providing competitive advantages. These researchers note that such innovations are subject to much uncertainty and risk; and innovative practices are often imported from outside of construction. Steel and Murray (2004) acknowledge that once the benefits of innovation are understood, efforts should be made to spread the innovation within organisational practice, but note the slow rate of diffusion of most innovations and advise that there may be a long time period from availability of an innovation to widespread use. Diffusion is therefore concerned with the spread of innovations. Various researchers identify the need for greater innovation diffusion research both within the construction industry (Larsen and Ballal, 2005; Widén and Hansson, 2007) and on construction projects (Harty, 2008). Gambatese and Hallowell (2011a, p515) identify a need for further research into the "*identification and dissemination of new technologies, systems and processes that have the potential to become innovations within the construction industry*". These researchers also identified the importance of evaluating the impacts and benefits of innovations, as well as undertaking research into their widespread use in the construction industry. This study responds to these calls and uses Rogers (2003) classic innovation diffusion theory to investigate further.

2.1.2 Rogers (2003) Diffusion of Innovation Theory

Everett Rodgers (2003) popularised the 'Diffusion of Innovations' theory of how, why, and at what rate, new ideas and technology spread through cultures. Since the first edition was published in 1962 the text has been cited over 83,000 times by scholars, and an explanation of several key points and terminology is necessary for purposes of framing the research. Some of the efforts of scholars, both in wider management literature and the construction management domain who have built upon Rogers work are discussed within the following section. Rogers defines diffusion as the "*process in which an innovation is communicated* *through certain channels over time among members of the social system"* (2003, p5). Innovation diffusion communication is primarily concerned with new ideas and is identified as being between multiple individuals, as a two-way process of convergence. In this definition, all four key elements are contained: the 'innovation'; its means of information transfer or dissemination through 'communication channels*'* (which can be personal, or non-personal such as mass media); across 'time'; amongst members of a structured set of interrelated units known as 'the social system'.

Throughout the text Rogers (2003) produces several concepts (identified by italics) for consideration, including:

- How members of the social system determine the rate of innovation adoption because of the *Perceived Attributes of* [the characteristics of the] *Innovation*. Specifically, these involve the *Relative Advantage; Compatibility; Complexity; Trialability;* and *Observability,* of the innovation. See Figure 2.1.

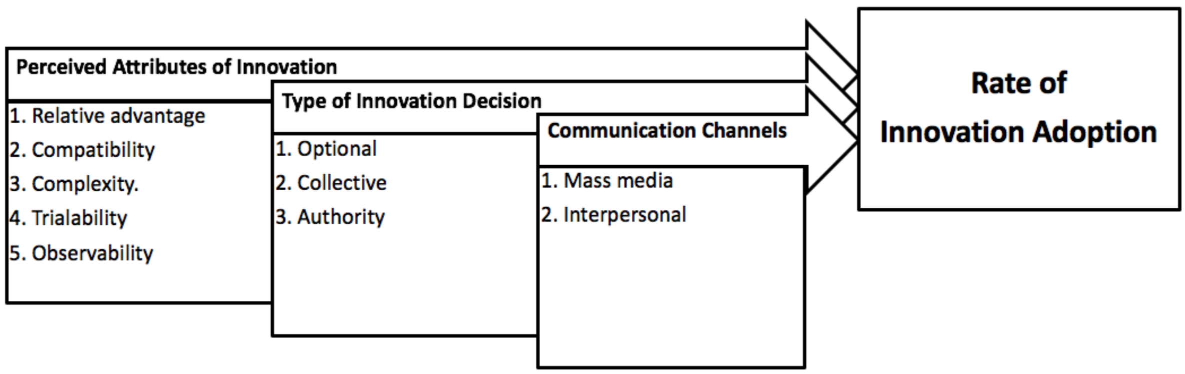

Figure 2.1: Independent and Dependent Diffusion Variables. Adapted from Rogers (2003)

- The *Innovation-decision process*[i]. This is the individual-centric process of innovation *Knowledge; Persuasion; Decision; Implementation* and *Confirmation*, which ultimately leads to adoption, or rejection of an innovation. Shown in Figure 2.2.

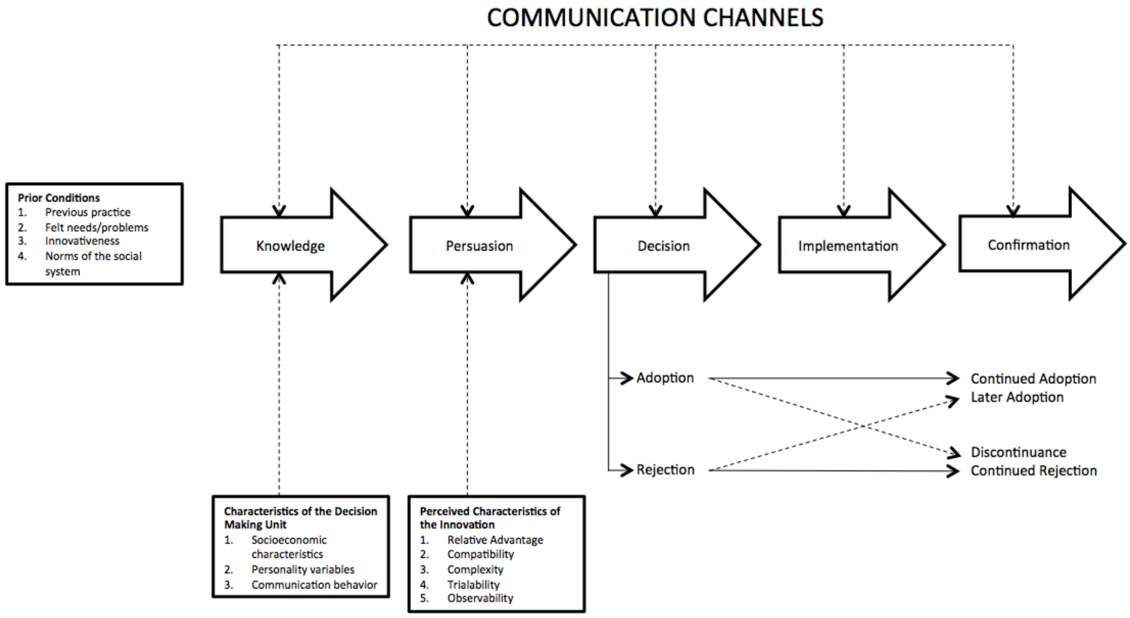

Figure 2.2: The innovation-decision process. Adapted from Rogers (2003)

- The effectiveness of communication channels[ii]: whilst non-personal channels can be highly effective in mass communication transfer of high value information, such as major worldwide news events, in innovation diffusion, individuals often place greater emphasis on the subjective judgement of near peers, particularly those who share certain personal characteristics or attributes (known as *homophily*), with the individual rather than in the objective judgement of experts, particularly *heterophilous* individuals - those who do not share personal characteristics with the individual.

- Concerning the rate of adoption, individuals become classified in various categories across a population depending upon the timing of their adoption. *Innovators* (2.5%); *Early Adopters* (13.5%) and the *Early Majority* (34%) contribute cumulatively to 50% of the available population, considered to be the point of *critical mass.* Following these are the*; Late Majority* (34%) and *Laggards* (16%). These adopter categories are illustrated in Figure 2.3.

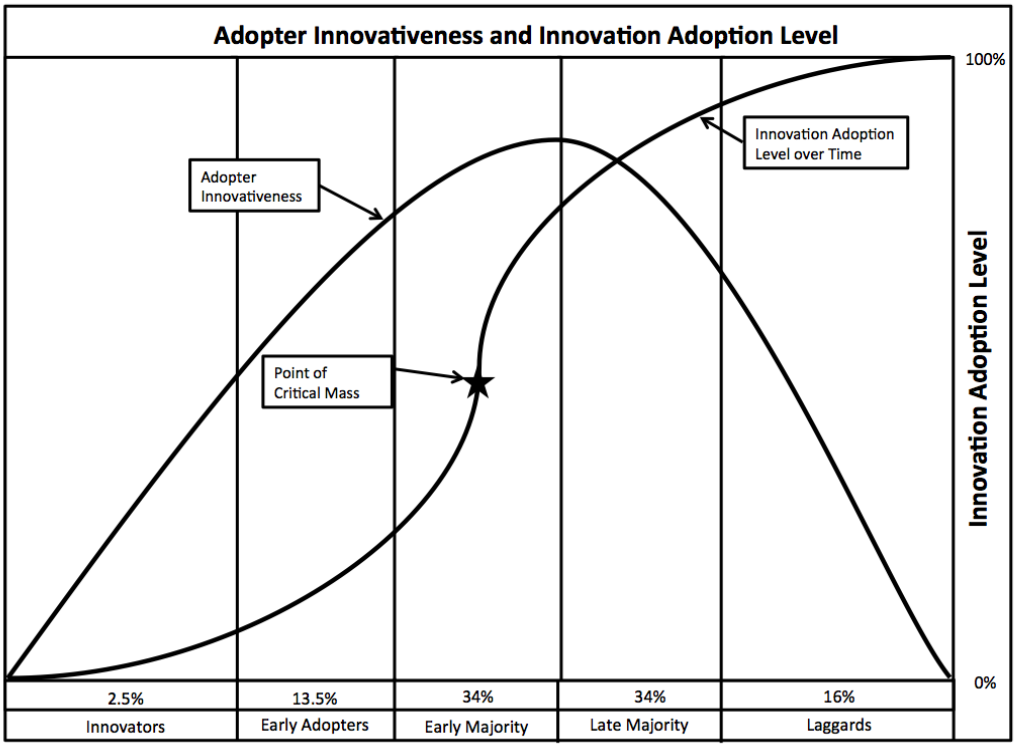

Figure 2.3: Innovation diffusion model. Adapted from Rogers (2003)

- The norms and rules within a social system constructed by individuals within that social system and key actors within the system include *Innovators, Opinion Leaders,* and *Change Agents.*
- Adopt-reject decisions can be classified as discrete decisions or connected decisions: *Optional Innovation-Decisions*, are made by individuals, *Collective Innovation-Decisions* are made by consensus, and for *Authority Innovation-Decisions*, adoption commitment is imposed by a

small number of controllers or influencers. In terms of connected decisions *Contingent Innovation-Decisions* are when more than one of the above individual innovation-decisions are made.

- Consequences, of both the intended positive and unintended negative varieties of an implemented innovation.

2.1.3 IDT research tradition and types

Rogers (2003) identified the major diffusion research traditions and categorised: the typical innovations studied in each tradition: the major methods of data gathering and analysis; the main unit of analysis; and the major types of findings. Rogers also advised on the changing research paradigms and network of diffusion researchers that he conceptualised as *invisible colleges*. An analysis of the major diffusion research traditions is presented in an adapted table from this text, presented below in Table 2.1.

In Chapter 3 there is a discussion about how construction management draws from both the natural and social sciences, and describes a recurring philosophical debate that has been held within the construction management research community since the mid 1990's regarding appropriate research methods and methodology for the construction management community, essentially a question of where does CM research 'fit'. It useful to note that with the exception of the *public health and medical sociology* research traditions, many of the above innovation types, methods and units of analysis related to diffusion studies (technology; new products; ICT; news; learning) are applicable to construction management diffusion research. In addition to categorising the established research traditions, Rogers was also able to present an overview of eight separate types of diffusion research. Analysis of the typology of diffusion research is presented overleaf in the adapted Table 2.2.

Table 2.1: Major diffusion research traditions. Table adapted from Rogers (2003)

Research tradition	**Typical innovations studied**	**Method of data gathering and analysis**	**Main unit of analysis**	**Types of findings**
Anthropology	Technological ideas	Participant and nonparticipant observation and case studies	Tribes/villages	Consequences of innovations; relative success of change agents
Sociologies	Wide varieties of ideas	Data from secondary sources; survey interviews and statistical analysis	Communities, individuals or other units	S-shaped adopter distribution; characteristics of the adopter categories; perceived attributes of innovations and their rate of adoption; communication channels by stages in the innovation-decision process; characteristics of opinion leaders
Education	Teaching and learning innovations	Questionnaires, survey interviews and statistical analysis	School systems; teachers or administrators	S-shaped adopter distribution; characteristics of the adopter categories
Public health and medical sociology	Medical and health ideas	Survey interviews and statistical analysis	Individuals or organisations	Opinion leadership in diffusion; characteristics of the adopter categories; communication channels by stages in the innovation-decision process
Communication	News events, technological innovations, new communication technologies	Survey interviews and statistical analysis	Individuals or organisations	Communication channels by stages in the innovation-decision process; characteristics of adopter categories and opinion leaders; diffusion networks
Management and marketing	New products	Survey interviews and statistical analysis; field experiments	Consumers	Characteristics of adopter categories, and opinion leadership in diffusion

Table 2.2: Types of diffusion research. Table adapted from Rogers (2003). Note: Column 4 also includes the approximate % of diffusion research that each type accounted for between 1962 - 2003 - proportions that generally remained consistent.

Type	Main dependant variable	Independent variables	Units of analysis *[followed by %]*
1	Earliness of knowing about an innovation by members of a social system	Characteristics of members (e.g., ‘cosmopoliteness’ communication channel behaviour)	Members of a social system (usually individuals) ***[5%]***
2	Rate of adoption of different innovations in a social system	Attributes of innovations (e.g., complexity, compatibility, et cetera) As perceived by members of the system	Innovations ***[1%]***
3	Innovativeness of members of a social system (the members may be individuals or organisations)	Characteristics of members (e.g., ‘cosmopoliteness’, communication channel behaviour, resources, social status, contact with change agents); system-level variables	Members of a social system (individuals or organisations) ***[58%]***
4	Opinion leadership in diffusing innovations	Characteristics of members (e.g., ‘Cosmopoliteness’); system norms and other system variables; communication channel behaviour	Members of a social system (usually individuals) ***[3%]***
5	Diffusion networks	Patterns in the network links between two or more members of the system	Dyadic network links connecting pairs of individuals (or organisations) in a system ***[less than 1%]***
6	Rate of adoption of innovations in different social systems	System norms; characteristics of the social system (e.g., concentration of opinion leadership); change agent variables (e.g., their strategies of change); types of innovation-decisions	Social systems ***[2%]***
7	Communication channel use (e.g., whether mass media or interpersonal)	Innovativeness and other characteristics of members of a social system (e.g., ‘cosmopoliteness’); system norms; attributes of innovation	Members of the system (or the innovation-decision) ***[7%]***
8	Consequences of an innovation	Characteristics of members; the nature of the social system; the nature and use of the innovation	Members or social systems or innovations ***[0.2%]***

2.1.4 Alignment of Research Objective 4 with IDT

Several of the dependent variables and unit of analyses classified by the above diffusion research types in Table 2.2 are particularly applicable to this study. Research Objective 4 is to investigate the diffusion of 4D BIM innovation within UK construction planning practice, and has five ('explore' and 'explain') sub-objectives which directly relate to established 'types' of diffusion research. It is useful at this stage to clearly map the relationship between these sub-objectives and IDT, as such:

- The construction planning functions that 4D BIM is principally being used for [*Relates to Type 8*].
- The extent of use of 4D BIM innovation [*Relates to Type 6*].
- The innovativeness of members of this construction social system [*Relates to Type 3*].
- The rate of adoption of 4D BIM innovation [*Relates to Type 2*].
- The consequences of 4D BIM innovation [*Relates to Type 8*].

2.1.5 Criticisms of IDT

It is also necessary to include what Rogers believes to be the main criticisms of diffusion research, which include:

- *Pro-innovation bias*: as innovation is implicitly a positive word, this type of bias is indicative of the assumption that an innovation should be diffused and should be adopted by members of the social system in a rapid manner.
- *Individual-blame bias*: a tendency for researchers to view the innovation from the perspective of the promoters of innovation rather than the potential adopters.

- *The Recall-problem*: the nature of this type of research often means that it can be problematic in measuring the time aspect of innovation adoption, particularly in terms of validity when relying upon self-reported data generated by research participants. A further associated issue is that typical research design used within diffusion research results in problems if attempting to determine causality between independent and dependent variables.
- *Equality* issues: as shown in the table above, the consequences of innovation diffusion somewhat ignored within diffusion research, particularly the consequences of any resulting increases in the socio-economic gap between those with higher and lower socio-economic status is in a social system.

Finally, to conclude this section on IDT, Rogers (2003) also stresses the need for researchers to consider the entire time frame of an innovation diffusion process, including decisions and events that occur prior to the point of the first adoption of an innovation.

2.1.6 Building upon diffusion research

Subsequent diffusion researchers have focused upon aspects of Rogers work. From the nature of innovation itself (Dodgson and Gann, 2010) to other core components including communication channels, time, the nature of social systems and the innovation diffusion process (Bass 1969; 2004; Moore, 2014). The impact of Rogers' adopter roles and the approximate percentages that these roles make up within a population (see Figure 2.1 above) has also been revisited within the literature. Whilst innovators have been described as the part of the population that will *"pretty much try anything"* (IGT, 2010), research has also focused upon the importance of the other adopter categories including the early adopters, late majority and laggards. Early adopters are important in diffusion because they actively disseminate information about the innovation and imitate innovative behaviour (Talk *et al*., 2014). The late majority are often derided for their relative lack of innovation take up, and deemed irrelevant to the success of a new innovation. Researchers explain that these population members may not have an actual need or a demand for the new innovation hence this is their *"barrier to engagement with it"* (Brewer and Gajendran, 2012). Laggards are not to be considered static laggards, as researchers (Goldenberg and Oreg, 2007) suggest that this group are often 'generation skippers' when it comes to multiple generations of a new innovation - known as 'the leapfrog effect' - and do end up being the newest of early adopters (or innovators) of a further new innovation probably due to the obsolesce of previous equipment or practices and needs development. Aranda-Mena and Wakefield (2006) note, "*Communication channels vary in importance according to the type of adopters. For example, mass media and expert knowledge has more influence on innovators, whereas personal networks are more important for late adopters".* Notable additions to diffusion innovation research include the work in Frank Bass who developed a mathematic model to help predict the diffusion of an innovation, and Geoffrey Moore (2014) who contended that in order for disruptive innovations in particular to be adopted, a chasm exists that must be crossed between the earliest adopters of an innovation (whom he refers to as 'enthusiasts' and 'visionaries') and the early majority (or 'pragmatists'), because of the differing expectations of these adopter categories.

2.1.7 A need for further research into construction innovation diffusion

As noted previously, research interest in innovation as specifically applied to the construction environment and project based firms has been steadily growing since the late 1990’s (Winch, 1998; Slaughter, 2000; Koskela and Vrijhoef, 2001; Gann and Salter, 2000; Gann, 2003). Miozzo and Dewick (2004) consider there to be a relative scarcity of analyses of innovation within construction. Reichstein, Salter and Gann (2005) stated that there had been few large-scale surveys of innovation in construction. Kale and Artidi (2010) noted that from 2004 a surge in construction studies exploring innovation diffusions had occurred, but few empirical studies had taken place during this period, and in those that had, recognised theoretical models of innovation diffusion were not being utilised as research methods despite their validity and use within wider academic community. These prior CM diffusion research efforts included: investigations into general diffusion of innovations theory within construction (Larsen and Ballal, 2005); diffusions of management innovations, such as lean construction (Green and May, 2005); and administrative innovations, such as quality management processes (Kale and Arditi, 2006; 2010). There is also much focus on technological innovations including: construction technology (Slaughter, 2000); general ICT (Acar, *et al*., 2005; Peansupap and Walker 2005; 2006; Panuwatwanich, Stewart and Mohammed, 2008; 2009); CAD (Kale and Arditi, 2005; 2010); 3D CAD (Harty, 2005; 2008; Taylor, 2007; Schweber and Harty, 2010); and BIM (Fox and Hietanen, 2007). Alternative diffusion research has also been undertaken making use of the likes of systems dynamics (Park, Nepal, and Dulaimi, 2004; Loosemore, 2014), and social network analysis (Larsen, 2011), however, despite consideration of such developments, use of classic innovation theory does remain an appropriate method for investigating the adoption of innovation in the UK Construction industry.

2.1.8 Section Summary

This first section of the literature review has discussed innovation and provided a primer on classic innovation diffusion theory. Notable studies on the diffusion of construction innovations have been identified, and the applicability of IDT to this study has been noted, thus satisfying **Research Objective 1** in examining classic innovation diffusion theory and its applicability to the construction industry. Before 4D BIM innovation can be discussed in greater detail, it is first necessary to consider in turn, construction planning in relation to time predictability, then introduce Building Information Modelling.

2.2 Construction planning and the time predictability problem.

This section of the work focuses primarily on the time predictability problem and is designed to satisfy **Research Objective 2** as it analyses the planning of construction projects within the context of poor industry time predictability. Project time predictability is affected by several of the elements identified throughout the remainder of the literature review (depicted in Figure 2.4 overleaf) and this section first introduces construction planning, then discusses the relevant aspects of planning that contribute toward the problem of time predictability.

2.2.1 Construction planning defined

Seminal planning literature focused upon broad research questions of 'what' is planning, 'why' is planning necessary, 'how' to plan, 'who' should do the planning and 'when' it should be done (Laufer and Tucker 1987; 1988; Laufer *et al.*, 1994), whist also specifically looking at planning failure, the impact of uncertainty and project objectives (Laufer and Tucker 1987; Howell, Laufer, and Ballard 1993; Winch 2010); and ways to improve the planning process (Laufer 1992; Faniran, Oluwoye and Lenard, 1994). These issues can be considered in relation to their impact upon time predictability. Fayol (1916) advises that planning is a function of management, stated, *"To manage is to forecast and plan, to organise, to command, to coordinate, and to control."* Laufer and Tucker (1987) identified three broad purposes or 'functions' of planning; The first of these is to assist the manager in giving direction. The second is to coordinate and communicate with the parties involved in the realisation of a construction project. The third function is to facilitate project control. Laufer and Tucker (1987) also discussed five distinct roles that planning plays, 'execution', 'coordination', 'control', 'forecasting' and 'optimisation', and noted that the forecasting and control functions are frequently given higher priority than execution planning for most contractors, with

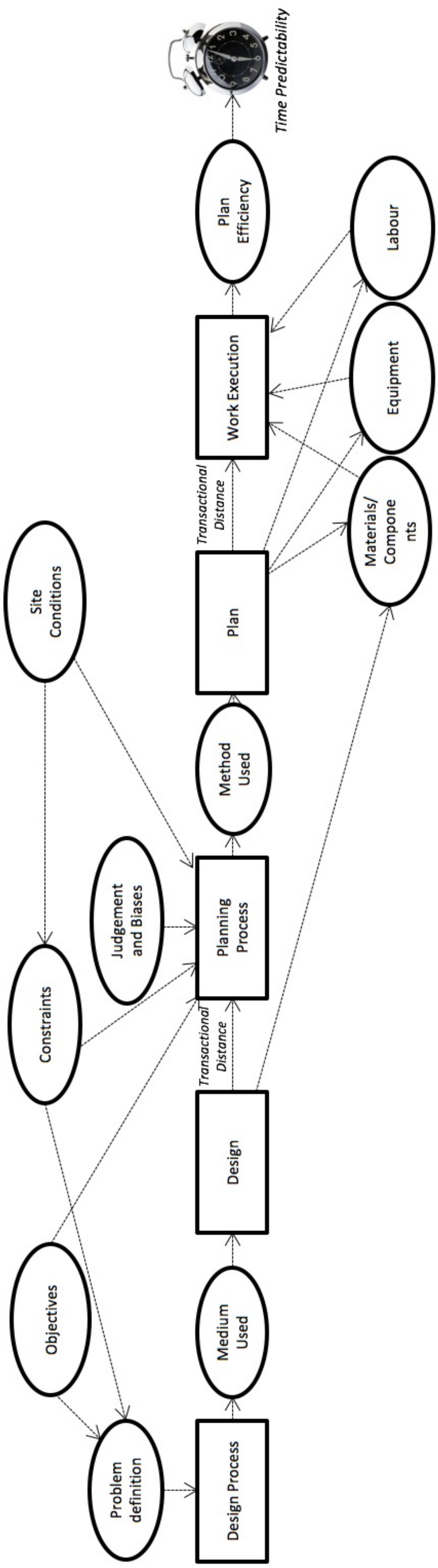

Figure 2.4: Determinants of time predictability (Researchers own).

time scheduling given priority particularly at the expense of methods planning. These researchers advised that this was most likely due to advances in computer applications; issues of training; and perceptions of the ability of management to be able to apply control functions to time.

Laufer *et al.* (1994) later revised their earlier ‘purpose’ definitions into different strands which occur throughout a projects life. These can be simplified as: set and understand objectives, and constraints; define and break down the required work; coordinate and integrate the inputs and decisions; analyse alternatives; prepare action plans; forecast performance; communicate the plan; monitor, review and control project execution; and learn from experience. Cooke and Williams (2009) similarly summarised the planning process as: gather information (typical examples of which include the establishment of key project dates and understanding of project constraints), establish key activities and events; assess how long these activities will take; establish any necessary logic and sequence for these activities; present the plan in a suitable medium (such as a to-do list, a time schedule or a diagram suitable for site logistics and layout planning). Laufer and Tucker (1987) also identified three of the major flaws in planning: ‘Focus’ - scheduling is overemphasised while methods planning is neglected (also supported by Faniran, Oluwoye and Lenard; 1994; Heesom and Mahdjoubi, 2004; Zwikael, 2009) ‘Role’ - control overshadows action planning; and ‘Process’ - decision-making proper gets almost all the attention, while the necessary steps prior to the following it are ignored. Factors such as inadequate decision making processes, and lack of appropriate emphasis on methods and action planning can be considered as contributing toward poor time predictability.

2.2.2 Accountability in planning.

The literature makes clear that no one individual retains control of planning on an individual project and such lack of accountability can be considered as a contributing factor to the time predictability problem. Hartmann and Vossebeld (2013) outlined the distinct challenges in planning the assembly of site constrained construction products requiring the integration of knowledge across multiple product co-creators and project actors. Planning occurs at multiple levels within temporary project organisations. At the highest level, the client and their representatives determine the scope of a project and its ‘goals’. These may then be negotiated with upper management levels of the appointed construction organisation. At the next level down, ‘means’ are determined, typically by middle management who guide the project as directed by upper-management. Further down, action ‘solutions’ are selected by day-to-day project level staff guided by middle-management (Laufer and Tucker 1987; Ballard, 1994; Winch and Kelsey, 2005). At project level, research undertaken to determine who is best placed to produce construction plans between the manager who runs the construction operations, or a dedicated resource such as a construction planner found that both manager and planner should work together, but factors that affect this collaboration include ‘time availability’ and ‘information gathering’ processes (Laufer and Tucker, 1988; Shapira and Laufer 1993; Winch and Kelsey, 2005; Johansen and Wilson, 2006). Both these parties typically possess part of the necessary information required for planning but neither party possesses all of the required information, thus requiring a degree of information transfer between the two. In addition, planning requires both ‘quality time’ and ‘large blocks of interrupted time’; both are in short supply for a typical construction manager (Styhre and Josephson 2006).

2.2.3 The impact of uncertainty upon time predictability

A major factor affecting the planning of construction work, and therefore the outcome, is uncertainty. Galbraith (1977) defined uncertainty as "*the difference between the amount of information required to perform the task and the amount of information already possessed by the organisation".* Uncertainty particularly affects any early planning of construction work. Howell, Laufer and Ballard (1993) showed that project decision makers and planners consistently face significant uncertainty in a project as late as the start of construction, and identified a distinction between uncertainty on what is to be built (the objectives), and how to build it (the means). Therefore, there is 'product' uncertainty and there is 'process' uncertainty. Faniran, Oluwoye and Lenard (1994, p487) contextualise uncertainty as the *"absence of relevant information for decision making during construction planning"*. Howell and Koskela (2000) commented, "*Uncertainty is often very high and subject to almost continuous change"* and noted that this continues throughout the onsite construction phase of a project. Some uncertainties stem from the nature of the construction process, yet other uncertainly focuses upon potential (sub)contractor performance during the course of the construction process (Kale and Arditi, 2001). Ford, Lander and Voyer, (2002) noted that uncertainty is 'dynamic' and referred to the *"evolution over time of the uncertain conditions"*. Winch and Kelsey (2005) mentioned difficulties with this due to the unquantifiable nature of uncertainty, and argued that while use may be made of statistical analysis or modelling methods to understand past events, these tools do not help predict future events. Winch (2010) later framed the issue of uncertainty as a key management dilemma and stated, "*The management of construction projects is a problem in information or rather a problem in the lack of information required for decision making*". Winch (2010) outlined the challenge of managing construction projects throughout their timeline in the context of uncertainty, in a concept he framed as *the dynamic reduction of uncertainty through time*, shown in Figure 2.5.

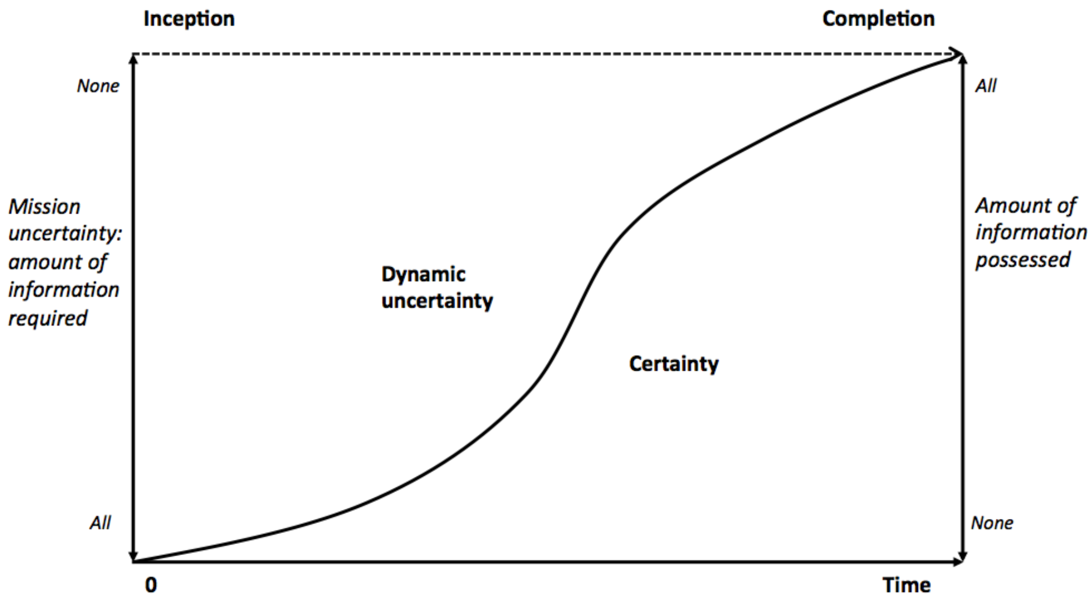

Figure 2.5: The dynamic reduction of uncertainty through time. Adapted from Winch (2010)

This means that the earlier the planning of construction work, the more uncertainty there is and therefore the lower the accuracy of the plan is likely to be (Laufer and Tucker, 1988; Mawdesley, Askew and O' Reilly, 1997; Johansen and Wilson 2006; Menches *et al.*, 2008). However, some early planning efforts are needed at this stage as it is understood that the ability to positively affect cost and time performance of a project significantly decreases over a projects timeline, with the greatest opportunity to influence being at the earliest design stages (Paulson Jr, 1976; Faniran, Oluwoye and Lenard, 1994; Winch and Kelsey, 2005; Winch 2010). This is illustrated in Figure 2.6.

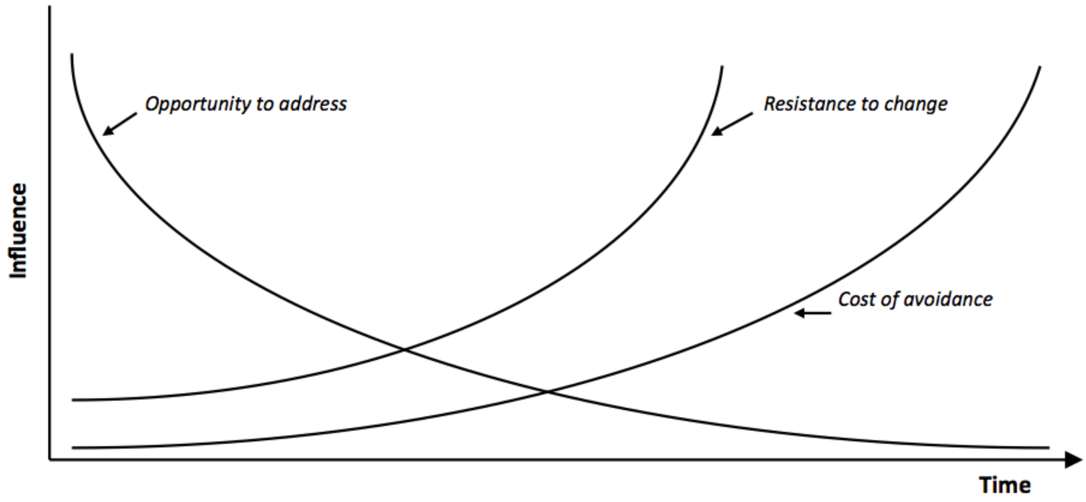

Figure 2.6: Decreasing management ability to address change through time. Figure adapted from the Paulson curve, also known as 'Level of Influence on Project Cost' (Paulson Jr, 1976, p588)

Early planning facilitates the shaping of project objectives and the identification of constraints (Laufer and Tucker, 1988). Howell, Laufer and Ballard (1993) noted that projects often commence without having clearly defined project objectives and that this occurs on all projects. Their research indicated that significant levels of 'objective-uncertainty' (defining clearly what is being built) appears to be consistent regardless of project size or type, whereas 'means-uncertainty' (how the work is to be undertaken) is lower on larger lump-sum projects (also, there is likely to be greater scrutiny of methods when undertaking larger value projects). Their work highlights that uncertainty on construction projects is common, and beliefs that project objectives are always fixed and determined at the outset of a project are not correct. Howell, Laufer and Ballard (1993) determined that uncertainty is to be expected even late into a project.

2.2.4 The optimum planning point

Concepts like 'the dynamic reduction of uncertainty through time', and the 'decreasing management ability to address change through time' lead to questions over when planning should be undertaken. The 'planning horizon' is identified as the time-span between planning and action (Laufer and Tucker, 1988) when attempting to determine the optimum moment when planning should be carried out, e.g. Should it be done at the very earliest stages of the project during the design stage? Or at post-bid stage? Or should planning occur during the midst of the on-site period to maximise gains from more collaborative planning processes? The literature reveals that the timing of planning influences the quality of the resulting plan, which directly affects time predictability.

Procurement strategy can dictate when planning occurs. Much literature identifies that planning of construction operations occurs 'post design' in the pre-construction period within traditional general contracting (TGC) arrangements. Relevant criticisms of TGC focus on how the separation of design and construction phases creates barriers to effective communication (Emmerson, 1962) and excludes construction expertise in design decisions (Ireland, 1985; Pearl, Bowen and Hall, 1997; Cain, 2003). Benefits of early collaboration between designers and constructors have been recognised and various relational project delivery arrangements (RPDA's) such as concurrent engineering (CE) and integrated project delivery (IPD) have been advocated to address these issues (Anumba, Baugh and Khalfan, 2002; Koskela, Howell and Lichtig, 2006; Raisbeck, Millie and Maher, 2010; Lahdenperä. 2012). Outside of procurement considerations, distinctions have also been made between 'planning levels' and 'project stages' when discussing the involvement of various parties within the construction planning process. Researchers (Shapira and Laufer, 1993; Ballard, 1994; Johansen and Wilson, 2006; Lee, Peña-Mora and Park, 2006) have identified two levels of planning within a contracting organisation as 'strategic/conceptual' planning and 'tactical/operational' planning. Strategic planning is the planning done at company level usually by management based in head office where operational planning usually pertains to project level planning. Set against these planning levels three project stages are identified: 'pre-bid planning' (PBP) which occurs prior to the submission of the tender proposal; 'pre-construction planning' (PCP) which starts immediately on award of the contract, and 'during-construction planning' (DCP).

Shapira and Laufer (1993) clarify that strategic planning occurs during PBP and PCP which addresses: 1) the identification of key project challenges whilst formulating potential solutions; 2) determining project constraints; 3) optimising the balance between the contractors end goals (time, cost, quality etc.), and; 4) making key project delivery decisions (for example the final selection of construction frame technology if the mode of procurement allows). Johansen and Wilson (2006) add that planning decisions made at this stage are concerned with design review, site investigation, and selection of the construction sequence and procurement of the major elements required for the execution of the work. Winch and Kelsey (2005) identify the principal actors who impact the PBP and PCP stages and categorised them as 'customers', 'suppliers', 'performers or 'constrainers' of the construction works.

PCP is the time period most usually associated with the outline planning of construction operations. Research identifying factors that impact upon the effectiveness of planning, has found that the quality of planning is likely to be improved the more time is invested prior to commencement of work on-site, particularly in activity definition and in project plan development (Zwikael, 2009), and in time spent systematically evaluating the most appropriate available construction methods (Faniran, Oluwoye and Lenard, 1994). These researchers also argued that time is well spent reviewing the original construction plan at regular intervals after construction work has commenced on site in the DCP phase. Site level DCP phase addresses production means such as major equipment and site layout; work methods, including immediate crew level resources; work sequence and project schedule; and the budget (Laufer, Howell and Rosenfeld, 1992).

In considering the timing of construction planning and its relationship with time predictability, Laufer and Tucker (1988, p346) questioned whether planning should occur *"well ahead of implementation to benefit from wielding greater influence",* or if planning should be held off *"until close to the start of work to secure greater planning accuracy"*. It has been revealed that early PCP requires ample and sufficient 'quality time', however it is now known that the greater the uncertainty when planning, the lower the planning accuracy. Winch and Kelsey (2005) reflected that the greater the time between the plan and implementation of operations, the greater the variance there is likely to be in cost and time performance and that planning future construction activities in fine detail, and that planning ahead *"more than three months …is futile*" (p142). Johansen and Wilson (2006) highlighted the problem of creating accurate plans at a stage when project design is incomplete and noted a reluctance at practitioners to accept requirements and purposes of 'first plans' and 'later plans' where collaborative techniques including Last Planner System (Ballard, 2000) could be used in the DPC phase. It is clear that a combination of strategic and tactical planning from the PBP and PCP stages that address goals and means, and tactical/operational planning that provide means and solutions from the DCP stages are needed to positively influence construction project time predictability. However, various aspects of complexity, such as size, construction methods and technology used; and the inefficient organisation of human resource (Love *et al.,* 2013; Olaniran *et al.,* 2015) can also negatively affect this.

2.2.5 The impact of complexity upon time predictability

Complexity involves a number of interacting entities and elements. The previous section of the literature review identified system complexity across industry and project levels, although this section is primarily concerned with planning complexity. Walker and Shen (2002) advise that project complexity has numerous dimensions including project scope and size. Williams (1999) argued that project complexity is characterised by structural uncertainty concerning the number and interdependence of elements, and general uncertainty concerning uncertainty around ‘goals’ and ‘means’. Succar, Sher and Williams (2013, p184), describe project complexity as a measure of the difficulties of designing and constructing a project and consider that project complexity can be determined through a *"collection of variables which include site constraints, shape of structure, scale, scope, skill availability, cost constraints, legal framework, logistics, etc"*.

Howell (1999 p5) discusses complexity within the context of construction planning, defining it as "*the number of pieces or activities that can interact"*. Seminal work by Gidado (1996) identified the continuous increase in the complexity of construction projects as one of the most difficult of issues facing planning practitioners and considered aspects of complexity around ‘work flow’ and ‘the individual task’ which both impact time predictability. For ‘work flow’

Gidado (1996) emphasises how management influence negatively impacts on project complexity by determining: 1) non-logical interdependences of different kinds of technologies; 2) rigidities of sequence between various operations, and: 3) purposeful compression of overlapping construction elements in order to shorten planned production time. For 'the individual task', Gidado (1996) explains that the primary constraints affecting individual tasks are inherent 'complexity' and 'uncertainty' factors associated with each task, arising from either the task itself, the environment, or the resources employed:

For complexity factors - Gidado (1996) provided three divisions:

- *Technical complexity*: tasks that are new or have not been performed before - yet are understood in principle, with suitable resources, and knowledge and skills able to be marshalled to undertake them/
- *Analysability*: tasks that are new or not well understood that will require concentrated efforts and preparation.
- *Task difficulty*: tasks that are not new, are well understood, do not require specialism, but are being performed in new environmental circumstances.

For uncertainty factors - four divisions were provided:

- Lack of *complete specification*: incomplete or poor-quality design information to execute a task.
- *Unfamiliarity*: either of the inputs or the environment.
- Lacking *uniformity of work*: relating to materials, teams, places and time.
- *Unpredictability of the environment*.

Gidado (1996) states that these *“seven inherent complexity and uncertainty factors may intersect with each other and with the environment in which they exist”*.

Issues related to ‘flow’ and the complexity of ‘the individual task’ was also considered in the early work of Koskela (1992; 1997), who rejects the traditional production philosophy of construction, where ‘inputs’, such as materials and labour, are simplistically processed into product ‘outputs’. Instead, Koskela argues for a new production philosophy that highlights the significance of ‘flow', the process that helps identify and eliminate non-value adding activities (i.e. waste)[iii2]. Koskela (1999) subsequently analyses the interactions between the individual construction task and three separate flows: the ‘material flow’, through the supply chain and to the site; the ‘location flow’, of the installers/operatives moving to each separate area of work, and: the ‘assembly flow’ i.e. the planned sequence of works.

In discussing the preconditions necessary for individual task execution, Koskela (1999) notes that a “*construction task is (usually) an assembly operation*”, and focuses on the inputs, and ‘flows’ to a construction task, identifying that there are at least seven preconditions that need to be ‘made ready’ in order to produce the desired task result. These are: 1) the construction design; 2) all components and materials; 3) the workers required to undertake the task; 4) their tools and equipment; 5); the working space; 6) the ‘connecting (predecessor) works’ that need to be available and sufficiently complete, and; 7) appropriate external conditions (e.g. no extreme temperatures or weather). If any one of these ‘inputs’

2 Koskela (2000) would return to the issue of formulating an explicit theory for construction, and in his doctoral work ultimately argues for the synthesis of several separate production theories, in a model that he termed the ‘transformation-flow-value (TFV) generation model of production’.

are lacking at the planned start time of a task, then the individual task may not be able to commence. Alternatively, it may be able to commence, but it will not be able to be completed. In construction, problems ‘making ready’ all of these ‘preconditions’ are common, which also adds to the variability in executing construction work at individual task level, and hence contributes to the time predictability problem.

Construction programmes, with their task combinations and connections, are complex systems. The volume of tasks alone can also be considered an indicator of planning complexity. This is evidenced in the literature where Liston, Fischer and Winograd (2001) reflect on a construction programme used in their research with 8,000 tasks. Dawood (2010) also describes a study that uses a sample of 3 selected projects and reveals that over 15,631 tasks were analysed from two of the projects analysed (total number of tasks analysed was not provided for the third). If issues of task volume, work flow, and the inputs, uncertainty and complexity factors associated with each task are indicators of programme complexity, then appreciating that each task may have multiple logical dependencies and different dependency types (Finish to Start; Start to Start; Start to Start with Lag etc.), means that the possible logical iterations also increases the complexity of the programme, “*the more complex the type of dependency, the greater the complexity*” (Williams, 1999). It is clear then that complexity factors create variability in the execution of construction work resulting in poor time predictability.

2.2.6 Traditional construction planning techniques and output.

Having introduced planning and discussed several factors affecting construction project time predictability, it is now appropriate to consider common techniques used in construction planning and the typical formats of construction planning output used. Much planning research has been directed toward attempts to improve planning techniques, but these efforts have not resulted in widespread adoption or have been able to significantly improve time predictability, and as such much of this research has been excluded here, save for a section providing a brief overview of relevant efforts. The section concludes by identifying how typical biases impact upon construction project time predictability and by listing common reasons why project delays are encountered.

2.2.7 Bar charts

Henry Gantt developed a hand-drawn method of communicating the planned timescale of activities using bars circa 1910-15. The 'Gantt chart' was used for the planning and control of shipbuilding activities for World War 1 production efforts (Tucker and Roberts, 2005). Such hand drawn 'bar-charts' are able to communicate: individual activity names and durations; timescales of individual phases or the entire project; and provide an indication of the construction sequence. What they do not communicate effectively, includes: the multitude of actual logical relationships or dependencies between activities; responsibility for undertaking work, and: the actual method of undertaking work, which is typically communicated using additional material such as an associated method statement document. Hand drawn bar charts have remained popular with construction foreman for their ease of preparation and apparent ease of understanding. For non-complex projects they can work well, as in their simplest form, the activity sequence is readily apparent and the relationships between activities can be easy to understand (Cullen and Nankervis, 1985; Winch, 2010). They also provide quick and easily understood methods of demonstrating planned versus actual performance when undertaking progress reporting. This is achieved either by shading percentage complete of the planned bar or, overlaying 'actual' bars - showing actual dates of activity commencement/completion, and the rate of progress as measured against baselined planned bars to see if any variation has occurred. The major deficiency in using hand-drawn bar charts is that as complexity increases, bar-charts fail to provide the type of information that is so often valuable for planning and scheduling as it becomes more difficult to show clear dependencies between activities (Hinze, 2008).

2.2.8 Critical Path Method (CPM)

Deficiencies in hand drawn bar charts for planning complex projects made organisations seek to developing more advanced methods of planning operations. Organisations such as DuPont and the US Navy developed hand-drawn network analysis techniques between the 1950's and 1970s. Adoption by the USA construction industry commenced in the early 1960s with UK organisations following the trend after a delay of 3 to 4 years; and developing countries took a further 8 to 10 years (Arditi and Koseoglu, 1983). Use of network analysis allows consideration of how project durations can be shortened by taking into account logic links such as the dependencies between individual activities and their predecessors and successor activities in order to calculate; non-critical activities, critical activities and the critical path of a project. Winch (2010) describes the various types of dependencies as being either 'technical', 'organisational' or 'spatial'. Float is *"the amount of time an activity can be delayed before it begins to delay the project* (Trauner, 2009), and the critical path is the longest run of activities through the network that establishes the minimal overall project duration. Trauner (2009) advises, *"The critical path is composed of a continuous chain of activities through the network schedule with zero total float".* Despite the benefits of plan optimisation generated by the CPM, hand-drawn network analysis techniques were not widely adopted within construction. The simple bar format, continued to be used as the most visual representation of communicating a construction plan. Arditi and Koseoglu (1983) found that factors that impact upon the successful use of network analysis within a contracting organisation included: the level of detail within the network; the mode of presenting the content of the network (with it should be noted, a preference for a bar chart type format being the preferred method for the receiver of the communication); the duration and extent of use of networks; site autonomy and the dynamics and formality of the manager and planner relationships.

In accordance with Moore's Law (1965)[3], wider technological advances allowed for an increase in the use of information and communication technologies (ICT) within construction. Computer aided planning methods became more widespread in the 1980s and networks analyses techniques employing CPM were able to be used as the underlying basis in computer-assisted planning and scheduling output. Early adopters were centralised planning and management personnel using relatively expensive office based microcomputers. By the1990s computing power had become affordable enough to be distributed to sites and used as an everyday tool by site based construction planners (Winch, 2010). Computer aided planning software produces the visual format of a bar chart combined with the underlying CPM calculations as shown in Figure 2.7.

3 Moore's Law (1965) states that every 18 to 24 months the capabilities of integrated computing circuits double and the price of such chips is cut in half.

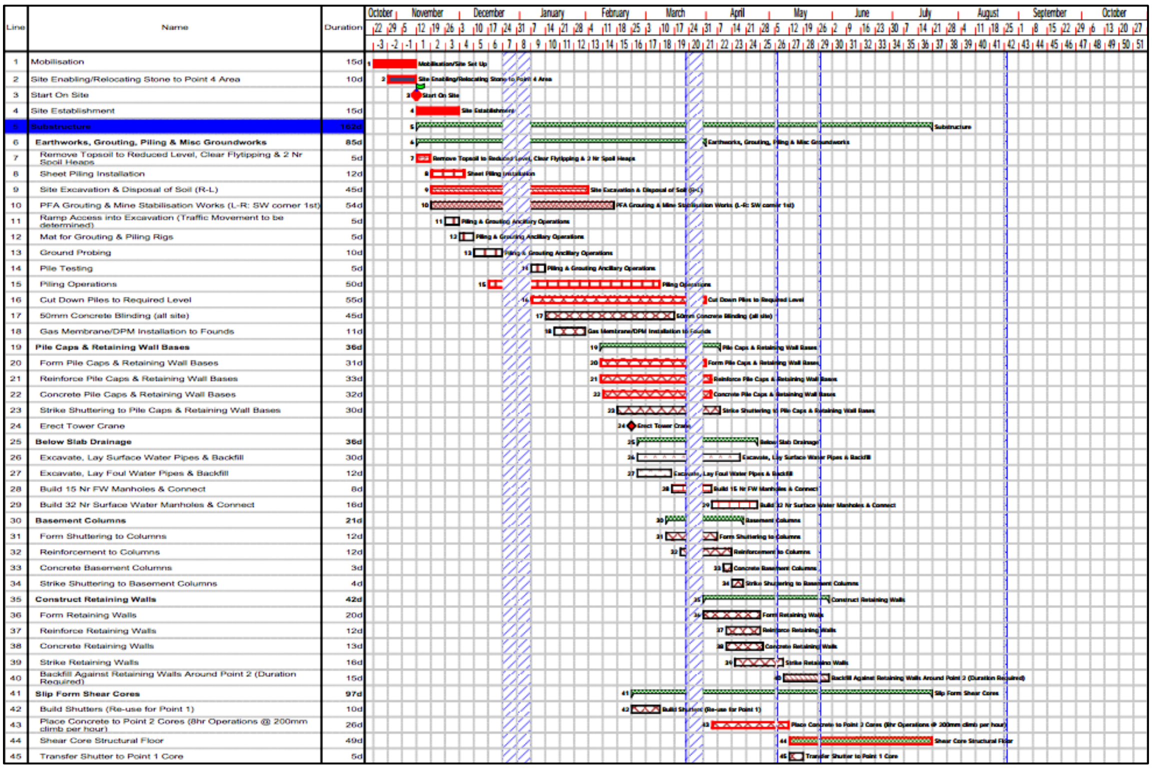

Figure 2.7: Construction programme (Researchers own, 2007)

This is a method that has remained longstanding with most construction planners. Mattilda and Abraham (1998) reported a 92.6% use of CPM techniques within the construction industry by the top 400 US contractors for the planning, scheduling and controlling of construction projects, and a decade later a UK survey undertaken by the CIOB (2008) established that the principle methods of time management on over 2000 projects were still mainly bar charts (54%) or networks (22%); indicating that CPM techniques continue to prevail.

2.2.9 Formats of Plans

Plans however can be communicated in a variety of different formats and managers have been encouraged to question standard planning solutions (Greenwood and Gledson, 2012). Although terms such as ‘plan’ and ‘programme’ are often used interchangeably within industry, the classic Gantt chart is merely a diagrammatical representation of a plan. Laufer *et al* (1994) identified that plans can be communicated in text (method statements; risk assessments used for information and for action planning); via technical diagrams (logistics plans or phasing or sequence plans); by organisational diagrams (indicating division of labour such as work breakdown structures or management charts); with time charts (such as the classic Gantt chart); or using tables which typically focus on time and money and used for control purposes. Whilst certain formats may be perceived to be better than others, receivers of information may also have predispositions for information formats due to prior experiences or as dictated by their brain function lateralisation i.e. right brain (visual imagery, creativity) / left brain (logic, numeracy). Users of construction information include 'inexperienced clients' (term as used by Gorse and Emmitt, 2007; Schweber and Haroglu, 2014) for clients unfamiliar with standard forms of construction production information) who should not be expected to form rapid understanding of design or construction intent using standard forms of construction information such as construction plans. Cullen and Nankervis (1985) also note that construction foremen are typically "*passive recipients of information*" who also want their planning material to be "*short term, simple and uncluttered*" – with a historic dislike of networks and other planning outputs provided by company planning specialists which often got *"consigned to the dustbin"*, before being re-planned by the supervisor. This is partially attributed to a 'Luddite factor' prevalent amongst many construction foremen - who held a hostile attitude to high technology in comparison to the more 'tried and trusted' way of doing things. Cullen and Nankervis (1985) concluded that "*the simpler the presentation of information, the more impact the message has"* and nearly 30 years on from this study a format even more appropriate for understanding method and sequence in the form of 4D BIM may be about to be promoted above the bar chart in terms of the ease of communicating construction planning.

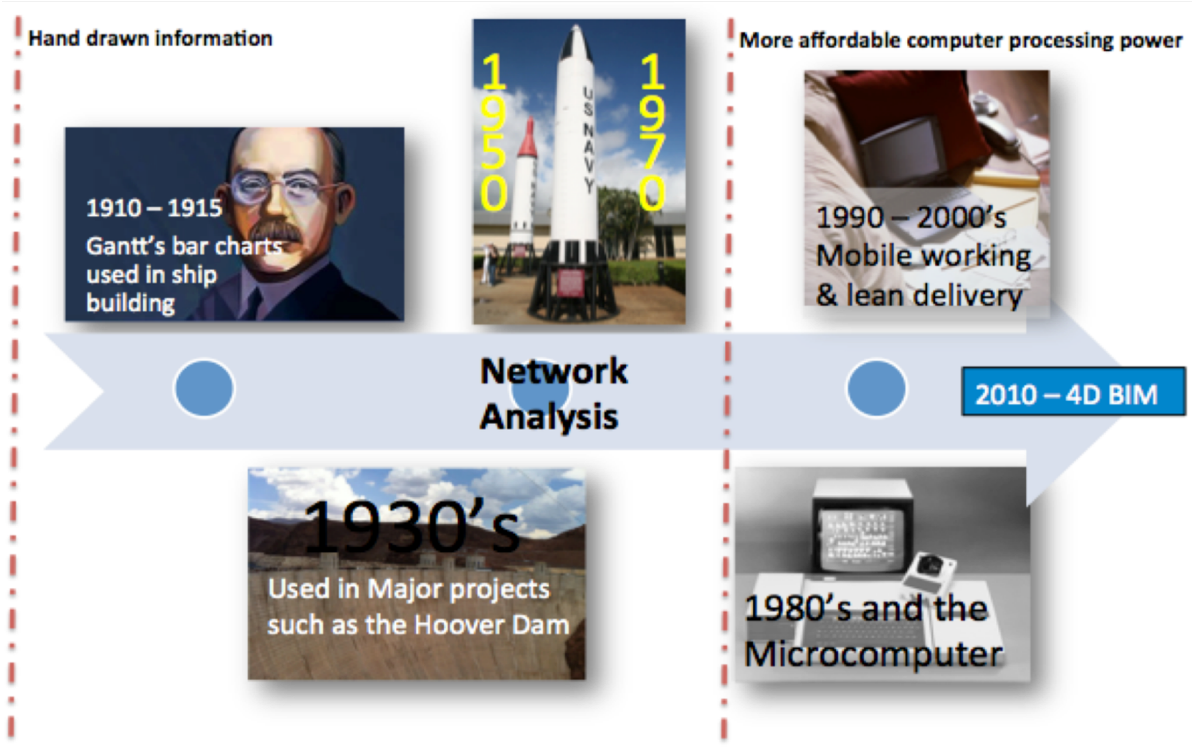

Figure 2.8: Development of construction planning tools

2.2.10 A brief overview of relevant planning research

Traditional planning methods rely largely upon deterministic techniques where known values for each individual activity duration (calculated using both material quantities and planned output rates - also known as productivity rates) are fed into the network in order to determine the critical path. The main sources of input for productivity rates used to determine task durations typically come from: data obtained first-hand from individual observations of an activity; through historic means - accessing a database of company performance measurement records; or by directly asking the organisation undertaking the work, often a subcontractor, how long they think the task will take to execute. If this occurs, the persons/organisations ultimately responsible for task planning/execution also have an opportunity to inflate or ‘pad out’ the task duration with ‘safety time’ (Rand, 2000; Steyn, 2001; Winch, 2010). Individual task durations therefore are a product of the resource output applied to the task, and as such can fluctuate substantially between the planned and actual durations. Winch and Kelsey, (2005) advised of limitations within traditional deterministic planning, and Touran (1986) advised that the use of deterministic methods to calculate activity durations can result in optimistic task estimates. These can result in a variance between planned task duration and actual task duration achieved, which contributes toward poor construction project time predictability.

Because task durations derived from deterministic methods are uncertain, research emphasis has frequently promoted probabilistic methods of planning as used in the program review and evaluation technique (PERT) which requires three values to be estimated when determining task duration, these are the ‘most-likely’, the ‘worst-case’ and the ‘best-case’ durations (Touran, 1986; Morris, 1997). Values distributed between these three estimates are assumed to be better, and therefore the probability of achieving a more accurate estimate of the entire project duration can also be calculated (Winch, 2010). As a direct consequence of the use of PERT; another probabilistic technique known as the Monte Carlo simulation was developed which provides both worst-case and best-case duration estimates for each individual task, which are then allocated randomly throughout the programme to calculate a normal distribution of the probability of the task or the whole project being completed on a particular date (Winch, 2010). Despite these advantages, researchers (Faniran, Oluwoye and Lenard, 1994; Winch 2010; Baldwin and Bordoli, 2014) have found that due to issues of complexity, probabilistic methods are not the norm amongst planners for task duration establishment and that a preference for deterministic CPM style techniques remains.

Tasks overrun their planned durations for a variety of reasons. One of the ways in which the control-based management systems impact negatively upon project time performance is the insistence of management of ensuring that tasks at least start by their planned early start dates even when key items such as the resources required for the completion of the task (available labour, materials, information, working space etc.) are not yet available (Winch, 2010). This is understandable as project level staff are held to account against dates established by ‘push’ based planning systems from master programmes established through ‘first planning’ by upper level management. By commencing each task on the planned early start date, management believe that gives sufficient impetus to subcontractors to commence, then work productively on the task and satisfy their contractual obligations. Unfortunately, this approach tends to elongate task durations to periods greater than what may have been achieved by holding off until necessary resources are available. Winch (2010) identifies that a site culture of ignoring the schedule because it is ‘always wrong’ has become a tradition. The early planning efforts shown in a contract or master schedule becomes divorced from the realities on site. The reliance on deterministic programming approaches, despite the resultant poor ‘hit rate’ (Dawood, 2010) further reinforces this attitude. A need for effective short term ‘pull’ based planning, to be undertaken for the benefit of site production level has been argued in the literature. Use of the last planner system (LPS) from the lean project delivery system (LPDS) is one of the innovations that has been viewed favourably outside of the lean construction research community. LPS is recognised as being useful both for short term look ahead planning, and for purposes of collaborative planning, having had some success in industry practices (Green and May, 2005; Winch, 2005; 2010; Baldwin and Bordoli, 2014). It is beneficial in managing crew-level plans that cannot be prepared far in advance of the actual operation because of uncertainties which are resolved only as the planned event approaches. Because of this, Ballard and Howell (1998b) argued that the individuals responsible for planning of near construction work - the last planners - a group usually led by the front line supervisor rather than construction planner or construction manager should make only ‘quality assignments’ available where tasks: are well defined (coordinated with other work); are ready to start (all constraints removed, design is complete, previous work is complete); sequenced (have immediate priority); and necessary resources are available (Ballard and Howell, 1998b; Winch and Kelsey, 2005: Baldwin and Bordoli, 2014). These researchers identify that construction tasks that do not meet these criteria should be deferred until ‘quality assignments’ can be made ready.

Conventional planning practices have particularly ignored location-based constraints in activity planning. As tasks are executed, not only are completed building products created, but working spaces are also created. These spaces alter many times during the construction process because of the work executed by the ‘parade of trades’ (Tommelein, Riley and Howell, 1999) that pass through these temporary work environments. Here, each trade manipulates the space to a greater or lesser degree by either creating enclosures (walls, floors, ceilings) adding layers (decoration) or opening up additional area (demolition and refurbishment works). Aside from site layout planning which is primarily focused upon placement of temporary works and logistical operations at the macro level, work site space planning is at the micro level has rarely been formally addressed in traditional construction planning outputs other than identification of the area through task naming conventions, example -‘*Piling @ GL 1-6/A-E*’. Experienced planners may consider spatial requirements needed for the execution of trade work, but traditional construction plan media has not effectively communicated these requirements. (Chau, Anson, and Zhang, 2003). Attempts to address this were made by the Critical Space Analysis (CSA) planning technique and the location based management system (LBMS). CSA tools enable a space-based analysis of construction operations to occur (North and Winch, 2002; Heesom and Mahdjoubi, 2002; 2004; Winch and North, 2006) by analysing the spatial configuration of the constructed product during the construction process (Dawood, *et al*., 2002). LBMS is an alternative to activity based planning methods championed within the lean movement because of improvements in visual management aspects. LBMS also focuses upon the organisation of resource logistics. In this method work location is used as the ‘unit of analysis’ for scheduling work (Kenley, and Seppänen, 2010). LBMS is about the elimination of workspace conflicts and continuity of work for trade operations and increased productivity. Recent research has investigated how LBMS can be combine with lean project delivery processes such as LPS (Seppänen, Ballard and Pesonen, 2010). However, location based planning methods such as CSA and LBMS have not been widely adopted in construction planning practice to date, although 4D technology now presents a feasible solution to assess location constraints and communicate detailed location based plans in order to improve project time performance.

2.2.11 Human biases

González *et al* (2013) identified poor planning, rather than unforeseeable events, as the greatest contributor to poor time performance. An ‘internal’ reason for poor planning 'hit rates’ may be the manifestation of the *planning fallacy*, the tendency to predict that tasks will be finished sooner than they actually are. The planning fallacy involves making best-case predictions for the future, despite personal experience and/or knowledge of previous similar tasks taking longer than expected (Kahneman and Tversky 1979; Buehler, Griffin and Ross, 1994; Buehler, Messervey, and Griffin, 2005; Kahneman 2011). A closely related phenomena is *optimism bias*[iv]*,* where the tendency to overestimate the possibilities of positive outcomes being realised and equally underestimate the possibilities of negative outcomes being realised occurs, i.e., there is overconfidence about the result of efforts having a positive outcome realised in comparison against the mean. (Lovallo and Kahneman, 2003; Buehler, Messervey and Griffin, 2005; Son and Rojas, 2010). Overconfidence in the precision of estimates has been described by Kahneman and Tversky (1979) both as a common bias, and a ’systematic’, rather than random ‘error of judgement’ that is habitually displayed by professionals and expert decision makers. Persons responsible for the planning of construction operations, when considering aspects of a particular task or project (duration, method etc.), are strongly influenced by the more distinctive aspects of a task or project, and are often encouraged to focus much of their efforts on facets of uniqueness and to plan from ‘first principles’. As a consequence, actors often fail to contextualise how similar tasks or projects were planned, and what the corresponding results of these efforts were. Research suggests that actors who suffer more from the planning fallacy are those who adopt a solely ‘internal perspective’ in the planning of work (Kahneman and Tversky 1979; Kahneman and Lovallo, 1993;

Buehler, Griffin and Ross, 1994; Kahneman 2011). They rely more upon ‘singular information’ - facts about the specific instance in hand, and use this data as the basis for working out methods and task durations, and as such they fail to “*give insufficient weight to distributional information*” (Kahneman and Tversky 1979). Whereas those who combine this approach with ‘external perspectives’ - seeking additional external frames of reference and consulting available data on the range of available outcomes in corresponding instances are much less likely to suffer from this bias. Several threads of research go further (Kahneman and Lovallo, 1993; Kahneman, 2011) and commit that use of ’the outside view’ alone i.e. the relevant statistical data, is likely to produce more realistic project timescale estimates overall. However, these researchers acknowledge that there is strong bias toward the ‘inside view’ even when there is available information that could support an ‘outside view’.

The poor ‘hit rate’ percentage achieved in construction task durations of circa 55% (Dawood, 2010; Howell, 2011) would indicate that there can be persistent occurrence of both the planning fallacy and optimism bias when planning construction tasks. Research of Buehler, Griffin and their collaborators (1994; 2003; 2005) reveals that individuals tend to future focus - concentrate on the task in hand rather than reflect on any negative personal experience or the experiences of others who may have completed similar tasks previously. Researchers have also demonstrated that when groups plan tasks together in a collaborative manner, the group dynamic tends to increase optimism and thereby worsen these effects (Kahneman and Lovallo, 1993; Buehler, Messervey, and Griffin, 2005; Kahneman, 2011), which contrasts with the aims of established collaborative planning techniques that attempt to improve the quality and accuracy of plans by increasing the participants involved in the process. A number of researchers in this field also call back to the dangers of groupthink as uncovered by Janis (1982, as cited by Kahneman and Lovallo, 1993; Kahneman, 2011 and Loosemore, 2014). This is concerning for 4D BIM effectiveness where visualisations are shown to promote team planning efforts, using visuals to elicit feedback and agreement about method, sequence and timescales.

2.2.12 Delays and disruptions

Finally, activity performance can also be affected by external factors resulting in unforeseen delays and/or disruptions that can also account for unpredictable task performance (González *et al*., 2013; Larsen *et al*., 2015). Disruption has occurred when a contractor is forced to duplicate effort, work out of sequence or bring back subcontractors to site to do more work. Carmichael, and Murray (2006) advise that disruption does not refer to the timing of the works but merely to a situation where the undertaking of the works is made more difficult because of 'hindrance' or 'prevention'. An activity can be said to be in delay, when it does not start and/or finish on time, or when the task is elongated, i.e., the work takes longer than originally anticipated (Williams, 2003). Delays can be caused by a number of issues including: partial or incomplete design at commencement of a task; changes or variations in the scope of works; discrepancies in contract documents or production documentation; previously unforeseen physical conditions affect the work; poor quality workmanship in activities that need to be remedied before continuing; inadequate planning of the work; inadequate resources for the site operations including material shortages, or plant breakdown; any accidents or incidents that occur on site; and any inclement weather that impedes upon site progress (see Harris, McCaffer, and Edum-Fotwe, 2010; Gündüz, Nielsen, and Özdemir, 2012; Love *et al*., 2013).

2.2.13 Section Summary

This section contributed toward **Research Objective 2** by analysing the planning of construction projects within the context of poor industry time predictability. It outlined the various factors arising from construction planning that affect construction project time predictability. It was found that planning takes place across several levels involving multiple personnel for different purposes including strategic/conceptual ‘goals’, and tactical/operational ‘means’ and ‘solutions’. No single actor is in possession of all required information and effective information transference is necessary. Control is afforded higher priority than execution planning; likewise, time scheduling is given priority over method planning. There is no optimum point to undertake planning. Planning quality increases the greater the time is invested prior to commencing on-site work, particularly in activity definition; and where efforts to systematically evaluate the range of suitable construction methods have been undertaken. Despite this, it is known that the greater the time between the planning and implementation of operations, the greater the variance there is likely to be in time performance. Uncertainty is a prime concern, as it manifests itself in many forms such as product-uncertainty; process-uncertainty; objective-uncertainty and means-uncertainty. Complexity factors also affect time performance throughout construction duration, and there is system complexity found across industry, project, programme and task levels.

Plans can be communicated in a variety of formats; however, the medium can get in the way of the message. An overview of several alternative construction planning practices was provided including: probabilistic methods such as PERT and Monte Carlo simulations; and collaborative and location based techniques. It was identified that despite the large range of alternative practices, bar charts produced with computer aided planning and scheduling software which perform critical path calculations remains the most used technique in industry. Factors that impact upon individual task 'hit rates' and overall project time predictability were discussed which included: pre-construction problems in obtaining accurate task duration data in the first instance; opportunistic padding out of task durations; phenomena including the planning fallacy and optimism bias; as well as common reasons for delay or disruption to the works.

The next section of the work focuses on aspects of the design process, showing how the generation of poor quality production information impacts upon time predictability of construction projects. Building Information Modelling is then more fully discussed, and thereafter 4D BIM is considered.

2.3 Building Information Modelling

BIM was introduced early into the thesis as a disruptive innovation. It has been positioned as a solution to the problems of managing construction project data, information and improving inefficient project processes. This section first explores problems associated with traditional design processes, considers several definitions of BIM to contextualise the subject, and introduces BIM from the perspective of an industry highly resistant to ICT innovation diffusion. Whilst key characteristics and benefits of BIM are discussed, the focus is retained on how BIM impacts upon the quality of construction industry production information and subsequently, how this impacts upon project time predictability.

2.3.1 Problems of existing process

Several aspects of the design process and the medium used for design contribute to the time predictability problem (refer Figure 2.4). Researchers (Tizani, 2007; Rekola, Kojima and Mäkeläinen, 2010; Crotty, 2012) have identified inefficiencies in traditional paper based design processes. Crotty (2012, p32) states that "*conventional drawing based design process generates inherently low quality unstructured information that is generally untrustworthy*". Crotty also discusses typical features of drawing based design information, that: 1) the overall design is transferred from the mind of the designer to either paper or to a 2D CAD system using systems such as drawn lines which contain no information, to represent the edges of design objects, or through using widely accepted symbols use to communicate various pieces of technical information, and; 2) to represent even a simple object adequately multiple project views including separate plans, sections and elevations must be produced and reproduced. If the design is updated, continual management is needed to ensure consistency across all types of project production documentation.

Tizani (2007) describes the information flows that occur within current design processes and identifies inefficiencies including: poor capture of formalised building requirements; rigidity of design process flow; problems associated with manual re-entry of data; compartmentalised decision making; lack of fidelity; minimal opportunities for design experimentation; lack of accommodation for late design changes and lack of design automation. At project inception, lead designers first establish the nature of the design problem at hand: be it 'well-defined', 'ill-defined' or 'wicked' (Churchman 1967; Winch, 2010; Emmitt and Ruikar, 2013). To do this, they extract the earliest non-formalised requirements through guided interactions with the client, to try to ensure that their needs will be met. Whilst current processes allow for the capture of subsequent design decisions taken, there is no widespread systematic framework in place for the initial capture of the ideas behind the building. Then, dictated by the selected project procurement strategy, a set order of the design activities that have to be carried out, before the information can be transferred down to other project participants is undertaken. This fragmented approach to managing the flow of design is criticised by Anumba, Baugh and Khalfan (2002) and identified as the 'over the wall' approach shown in Figure 2.9.

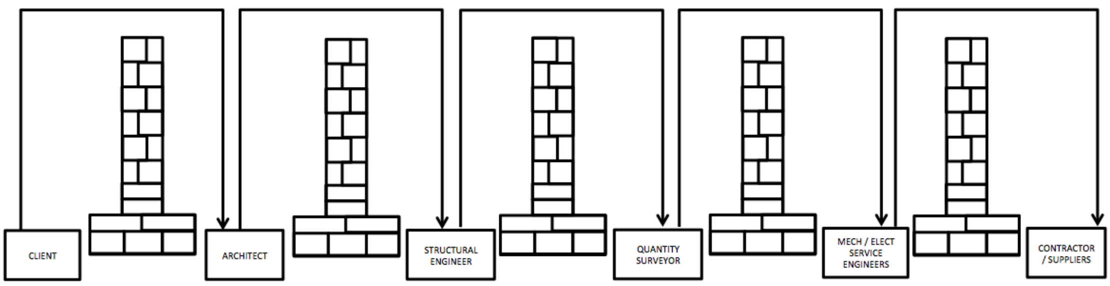

Figure 2.9: The 'over the wall' approach. Adapted from Anumba, Baugh and Khalfan (2002)

Once each identified area of the design has been produced, the recipient of the design information has to manually interpret the information in order to be able to make judgements. Because of the quality of the drawing that is presented to them, they may also have to make several assumptions which may lead to misinterpretations. Even if a drawing is sound, the recipient may not have the necessary technical skills to be able to interpret the information. The receiver of the information will also need all of the multiple project views available and correct to the latest revision to fully understand the design. Checking occurs either on an ad-hoc basis or in scheduled design review meetings. The frequency of such meetings could add time delay to this process, affecting overall project timing. Checking is done to ensure that the design is ‘clear’, ‘correct’, ‘consistent’, ‘coordinated’ with the associated design information (which may have been created by another producer) and ‘complete’ (fit for purpose). “*To carry out these checks effectively and consistently takes time and requires extraordinarily high, but generally unacknowledged, levels of skill, discipline and judgement. Such talents are rare and often unavoidable on fast moving projects which means that fundamental mistakes are often made"* (Crotty, 2012, p32).

Should the information be successfully interpreted by the receiver, the format in which it has been received, might mean that the relevant design information (the value to them) might have to be manually re-entered by the receiver into a separate company system. This checking, manual entry and logging of receipt of design also adds time to the design process, creates unnecessary costs, and a brings in the potential for user error, from misinterpretation during re-input (Tizani, 2007; Crotty, 2012). Tizani (2007) also discusses how design decisions are often made in isolation, or how they can be made too early without having access to the full information which would have been provided later in the process. This is because designers often make initial decisions that have adverse impacts upon other areas of the project design later in the process that could easily have been avoided, if the impacts of these decisions could be identified.

Emmitt and Ruikar (2013) identify how there are minimal opportunities for innovation, learning and experimentation within the design process, because of the fast track nature of modern construction projects. This is thought to be true even for projects with longer design durations, or where the design in not significantly overlapped with other process such as procurement, tendering and construction this occurs. This occurs because several design disciplines often must provide input into even the most basic of design activities and their co-ordination requires much time and skilled resource. Traditional control techniques are used to squeeze this period and reach final decisions as soon as possible. "*This reduces the amount of design iteration that may be carried out, which effectively stifles creativity. This in turn leads to the development of potentially less efficient designs"* (Tizani, 2012, p25). Because of such process rigidity, project teams, particularly when contractor led are unlikely to welcome late design changes that arise, even those that may be of benefit to the building product.

All of the above indicates that traditional means of generating and managing construction project design is inefficient and ineffective. BIM has been recognised as a potential solution to these types of problems. Project information is entered once and re-used many times throughout the project lifecycle, and because of this, much process waste can be eliminated. Sebastian (2011, p180) notes that "*BIM in its ultimate form, as a shared digital representation founded on open standards for interoperability, can become a virtual information model to be handed from the design team to the contractor and subcontractors and then to* *the client*". As such, focused use of BIM can facilitate improvements in construction project time predictability.

2.3.2 BIM defined.

van Nederveen and Tolman (1992) are credited as the first researchers to use the term 'Building Information Modelling' in an academic publication, and commentators such as U.S Industry analyst Jerry Laiserin subsequently popularised the term from around 2002. Laiserin's preferred definition (as cited in Forbes and Ahmed, 2010) is that BIM is a "*digital representation of the building process to facilitate exchange and interoperability of information in digital format*". Autodesk (2002) produced a 'white paper' that provided the following characteristics of BIM solutions "*(1) They create and operate on digital databases for collaboration. (2) They manage change throughout those databases so that a change to any part of the database is coordinated in all other parts. (3) They capture and preserve information for reuse by additional industry-specific applications".* This source also lists the benefits of use as "*higher quality work, greater speed and productivity and lower cost for building industry professionals in the design, construction, and operation of buildings"*. Charles 'Chuck' Eastman is a recognised authority on BIM having worked in this area since the 1970's, and published extensively on the subject under his originally preferred term 'Building Product Model'. Eastman *et al.,* (2011 p16) offer the definition *"…a modelling technology and associated set of processes to produce, communicate and analyse building models"*, and list that BIMs are typified by:

- "*Building components that are represented with digital representations (objects) that carry computable graphic and data attributes that identify* *them to software applications, as well as parametric rules that allow them to be manipulated in an intelligent fashion.*

- *Components that include data that describe how they behave, as needed for analyses and work processes, for example takeoff, specification and energy analysis.*
- *Consistent and non-redundant data such that changes to component data are represented in all views of the component and the assemblies of which it is a part.*
- *Coordinated data such that all views of a model are represented in a coordinated way*".

BIM is employed both as a noun and as a verb. The noun is applied to the model itself – in essence a database - and the verb applying to aspects of the process. Examples include definitions that specify that BIM is *"… a repository that stores all the data 'objects' with each object being described only once […] graphical and non-graphical documents such as drawings and specifications, schedules and other data respectively are included. Changes to each item are made in only one place and so the project participant sees the same information in the repository"* (Lee and Sexton, 2007) as well as *"… an object-oriented, AEC-specific model – a digital representation of a building to facilitate exchange and interoperability of information in digital format* (Kiviniemi *et al.,* 2008, as cited in Rekola, Kojima and Mäkeläinen, 2010). The term building information modelling is also considered to include work flow processes of exchanging information and working on the BIMs (Succar *et al.,* 2007) it is *".. not a thing or type of software but human activity that ultimately involves broad process change in construction"* (Eastman *et al.,* 2011 p353).

Several sources consider that the multiplicity of BIM definitions create misinterpretation and ambiguities which ultimately hinders the rate of adoption (Aranda-Mena *et al*., 2008; Zuppa, Issa and Suermann, 2009; Barlish and Sullivan, 2012; Demian and Walters, 2014; Miettinen and Paavola, 2014). One common definition emphasises the process related aspects:

> *"BIM is a process involving the structured sharing and coordination of digital information about a building project throughout its entire lifecycle, from design through procurement and construction and beyond, into the operation and management stage. This involves the use of coordinated 3D design models enriched with data which are created and managed using a range of interoperable technologies. BIM allows the virtual design, construction and operation of a building by developing and testing a digital prototype in advance of its physical realisation, thus delivering greater cost certainty, eliminating error, improving programme duration and reducing risk"* (BIM Academy, no date).

There have been several attempts made to create standard definitions. One early attempt at governmental level at creating a National BIM standard in the United States was provided by the National Institute of Building Sciences:

> *"A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward"* (NIBS, 2007).

This definition was also used by The American Institute of Architects (AIA) and has been cited subsequently in several academic sources (Isikdag *et al.,* 2007; Aranda-Mena *et al.,* 2008; McAdam, 2010; Sebastian, 2011; Barlish and Sullivan, 2012). This NIBS definition was subsequently adapted in the UK by bodies responsible for providing best practice guidance such as the Construction Project Information Committee (CPIC), BuildingSMART and the Royal Institute of British Architects (RIBA), who jointly proposed this wording as a starting point for discussion and refinement:

> *"Building Information Modelling is digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition".*

This wording was used in the *Strategy Paper for the Government Construction Client Group* (BIWG, 2011), in a report that preceded the official Government Construction Strategy.

2.3.3 Mandated BIM innovation adoption

The BIM Industry Working Group (BIWG) was tasked by the Department for Business Innovation and Skills (BIS) and the Efficiency Reform Group (ERG) from the Cabinet Office with reviewing the benefits of BIM in use within UK building and infrastructure and the resulting report recommended a strategy to '*increase BIM take-up over a five-year horizon as part of the joint plan to improve the performance of the government estate in terms of its cost, value and carbon performance'* (BIM Industry Working Group, 2011). The Government Construction Strategy itself stated only that *"Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016"* (HM Government, 2011), although this was then widely reported as all centrally procured Government contracts from 2016 requiring a standard of 'Level 2' BIM (CRI, 2011), when these levels had been only discussed in the previous BIWG Document (2011 levels shown in Figure 2.10). Despite this perception, it was made clear in a series of subsequent industrial strategy publications that the government was fully committed to being "*a global leader in the exploitation of this technology and […] as a supplier of BIM services and software by developing the UK's capability […]"* (HM Government, 2012), and that the use of BIM could help facilitate with the meeting of several industry performance aspirations, including those of 'lower costs' 'faster delivery', 'lower emissions' and 'improvement in exports' (HM Government, 2013).

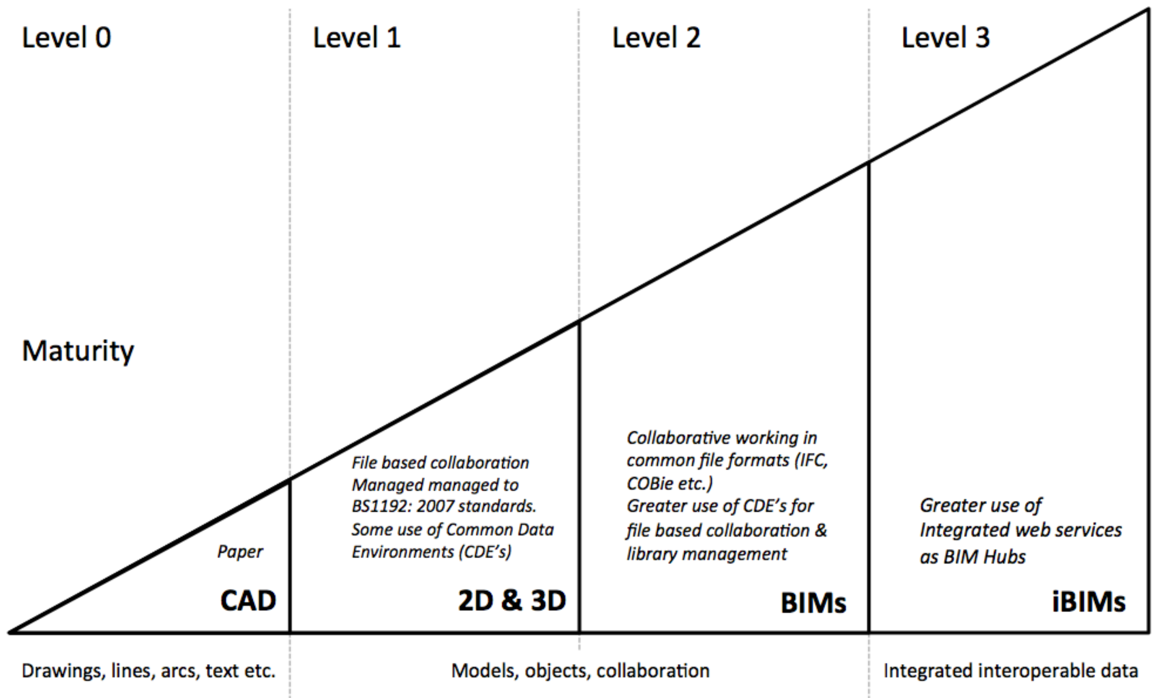

Figure 2.10: Bew-Richards BIM Maturity Wedge (Adapted from BIWG, 2011)

2.3.4 The evolution of 'BIM Levels'

Definitions of BIM levels have also continued to evolve (CRI, 2011; BSI 2013; 2014). An early definition of Level 2 was reported as being *"Managed 3D environment held in separate discipline 'BIM' tools with attached data. Commercial data managed by an ERP. Integration on the basis of proprietary interfaces or bespoke middleware could be regarded as 'pBIM' (proprietary). The approach may utilise 4D programme data and 5D cost elements as well as feed operational systems"* (BIWG, 2011; CRI, 2011; BSI 2013; 2014). It was reported that Level 2 BIM was distinguished by file-based, rather than paper-based collaboration. Definitions continued to evolve affected by factors such as: increased industry engagement; the rate of technological changes, and: increasing knowledge base and adoption levels. It was noted that *"Level 2 practice will continue to evolve and that the scope of information sharing and exchange will vary from project to project. For this reason, it can be anticipated that the definition of Level 2 BIM will continue to evolve around the core principle* *of the shared use of individually authored models in a common data environment"* (BSI 2013, p ix). Accordingly, the National Building Specification (NBS) subsequently published guidance about the concepts of BIM Levels (NBS, 2014a), which has been adapted and simplified below:

- **Level 0:** *"… effectively means no collaboration. 2D CAD drafting only is utilised, mainly for Production Information. Output and distribution is via paper or electronic prints, or a mixture of both … "*
- **Level 1:** *"… typically comprises a mixture of 3D CAD for concept work, and 2D for drafting of statutory approval documentation and Production Information. CAD standards are managed to BS 1192:2007, and electronic sharing of data is carried out from a common data environment (CDE), often managed by the contractor. There is no collaboration between different disciplines – each publishes and maintains its own data."*
- **Level 2:** *"…is distinguished by collaborative working – all parties use their own 3D CAD models, but not necessarily working on a single, shared model. The collaboration comes in the form of how the information is exchanged between different parties – and is the crucial aspect of this level. Design information is shared through a common file format, which enables any organisation to be able to combine that data with their own in order to make a federated BIM model, and to carry out interrogative checks on it. Hence any CAD software that each party used must be capable of exporting to one of the common file formats such as IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange). This is the method of working that has been set*

as a minimum target by the UK government for all work on public-sector work, by 2016.

- **Level 3** - *"… represents full collaboration between all disciplines by means of using a single, shared project model which is held in a centralised repository. All parties can access and modify that same model, and the benefit is that it removes the final layer of risk for conflicting information…"*

2.3.5 Historic AEC industry resistance to ICT innovation

Having considered problems with the design process then defined BIM and identified the UK Government mandate for BIM adoption, there is a need to consider BIM from the perspective of an industry highly resistant to ICT innovation diffusion. Crotty (2012) discusses how construction lags behind most significant economic sectors which have been radically transformed through the implementation of information technologies. These have afforded the embedding and management of human knowledge to facilitate value creation. Despite research into the positive impacts of ICT's, such as user satisfaction (Jacobsson and Linderoth, 2012); production cost advantages (Van der Vlist, Vrolijk, and Dewulf, 2014) and benefits of collaborative technologies (Emmitt and Ruikar, 2013), much construction research has emphasised the slow rate of ICT innovation diffusion (Peansupap and Walker, 2006) and resistance of the industry to adopting new technologies (Brandon *et al.,* 2005; Davis and Songer, 2008; Dawood, 2010; Underwood and Isikdag, 2011; Brewer and Gajendran, 2012). Problems of technology acceptance are not unique to construction (Venkatesh *et al*., 2003), however as identified in the multitude of definitions, the adoption of BIM requires more than just the acceptance of technology. Taking a cue from Malcolm Gladwell who popularised the term, Brandon *et al.,* (2005) speculated about how, and when, construction would reach the ‘tipping point’ and embrace greater usage of information communication technologies, and discussed the how to tip the balance for an “*accelerated penetration of information technologies into the construction industry*”. Dawood (2010) considered the AEC industry to be the largest in the world, yet acknowledges that it is “*often described as a slow adopter of new Information Technologies*” and that the industry is, “*by nature, information based. …* [therefore] *… the potential of IT applications is huge in terms of improving management practices, communication, and overall productivity”*. Underwood and Isikdag, (2011) believed that “*there is still a long way to go and much to do in terms of realising the full potential of these emerging technologies in line with the efficiencies and performance improvement that are being witnessed in other sectors*”.

In addition to industry-level, the adoption of such ICT innovations must also be considered from an organisational change perspective. Senior (2010) identifies three factors of organisational change, which are: the rate of occurrence of change, identification of how change manifests itself, and the scale of change. In a review of literature associated with the rate of occurrence of change, Todnem (2005) produced a spectrum ranging from ‘discontinuous change’, which are single events resulting in rapid change, through to ‘bumpy continuous change’, which are more regular organisational and operational changes with periods of stability disrupted by accelerated changes. Change can manifest itself within an organisation either as ‘planned’ or ‘emergent’. The planned approach to change is a control oriented, top-down approach whereas the emergent approach is bottom up, more responsive to external and internal environment stimulus and therefore more applicable to construction organisations operating in environments of uncertainty. Notable models of emergent change within the literature include Ten Commandments for Executing Change (Kanter *et al*., 2001); Seven Steps (Luecke, 2003), and Eight-Stage Process for Successful Organisational Transformation (Kotter, 2012). Todnem (2005) identified the scale of change ranges from ‘fine-tuning/convergent’, ‘incremental’, ‘modular’ (aka ‘radical’) and ‘corporate’ change, where organisational missions and values are altered. When considering the adoption of BIM-innovation from the perspective of organisational change theory the rate can be categorised as discontinuous, the approach as emergent and the scale as radical.

Jacobsson and Lineroth (2010) noted that it was necessary to distinguish between the adoption and longitudinal use of such ICT's innovations as BIM in a singular permanent construction related organisation, and their short-term focused use for project delivery by TPO’s requiring inter-organisational collaborations that cross organisational boundaries. These researchers concluded that unless project benefits were immediately realised, project rather than organisational targeted ICT innovations are likely to be rejected because of time-constraint emphasis of construction projects.

2.3.6 Benefits

Whilst headline benefits include improvements in collaboration (Sebastian, 2011) and reductions in the various forms of product and process waste and improvements in design coordination (Eastman et al., 2011; Huang et al., 2009; Rekola et al., 2010). It is appropriate here to focus more on the benefits that BIM can bring in relation to construction time predictability.

The timescale of design periods can be reduced and production information quality can be improved through integrated working practices, greater use can be made of concurrent design and coordination efforts, and parametric design which facilitates use of the behavioural capabilities of parametrically modelled intelligent objects. BIM-based design allows for changes made anywhere within the model to automatically propagate to all model views and resultant production documentation (such as drawings and schedules) eliminating inaccuracies created by having to source multiple project views and verify their trustworthiness. For information recipients, the parametric nature of BIM-based design greatly reduces inconsistencies arising in several corresponding and related documents, and allows particular aspects of design to be understood in context as part of the wider system (Crotty, 2012; Succar, Sher and Williams 2012). Greater collective understanding of design intent reduces the typical volume of design changes made and contractor requests for information (RFI's) needed in comparison against traditional design practices (Eastman *et al*., 2011). Additionally, as design 'output' is used as one of the inputs in the construction planning process (See Figure 2.11 overleaf), any increases in the fidelity of production information will help minimise uncertainty and aid task and project time predictability.

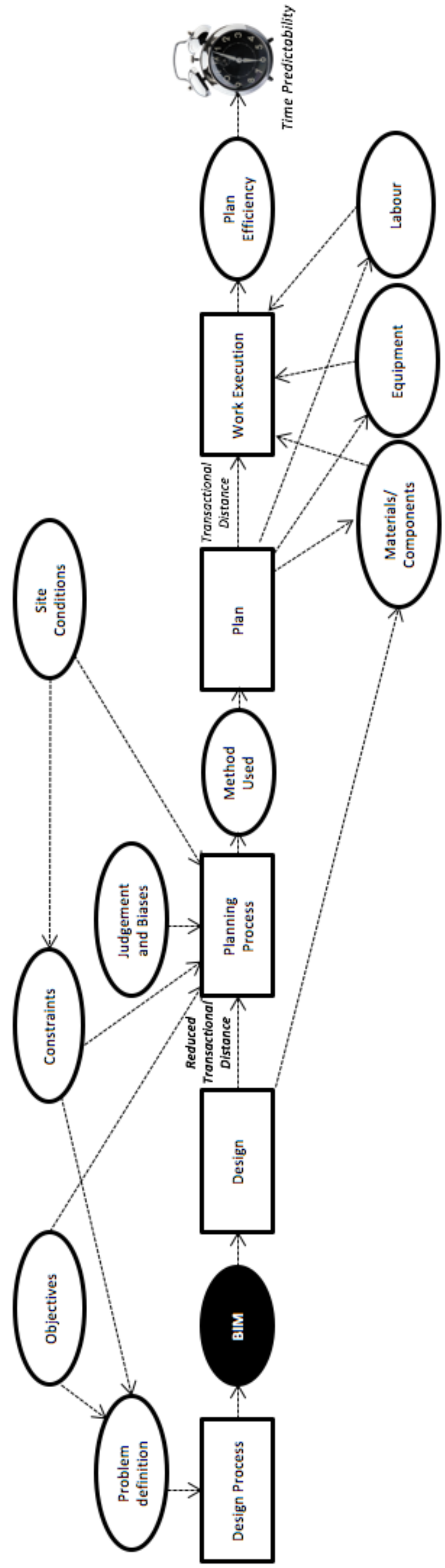

Figure 2.11: Determinants of time predictability using BIM Innovation.

Uncertainty can be reduced for construction site operations through the use of virtual prototyping. This method is used in a variety of sectors such as engineering and manufacturing to facilitate product development. The purpose of virtual prototyping is to validate a design before creating it (Wang, 2002). Virtual prototyping in construction uses integrated product and process modelling to support the planning of construction projects within a virtual environment (Huang et al., 2007, 2009; Li et al., 2008). Undertaking Virtual Construction (VC) processes, before physical construction is a key benefit for constructors (Waly and Thabet, 2003; Huang *et al*., 2007).

One benefit of virtual prototyping an entire building is that the use of 'clash' or 'interference' checking can be facilitated. 'clash-detection' is considered as being a key construction benefit that assists in the coordination of building systems and work package trades, helping to resolve expensive coordination errors. (Davies and Harty, 2013a; Poirier et al., 2015). This functionality within BIM platforms allow rule-based tests to be created so that unwanted interference or 'clashes' between sets of components or individual objects across federated models can be identified (Hardin, 2009). *"Space conflicts are a significant source of construction site problems and can be largely eliminated with careful clash detection using an accurate and detailed model"* (Eastman *et al*., 2011, p274). This process will be undertaken throughout multiple project stages including the design, pre-construction, and construction phases. Traditional coordination of building components is facilitated in design reviews, overlaying production information and making use of light tables. Onsite-coordination necessitates side-by-side review of multiple floor plans, sections, elevations and details. These methods are prone to error, dependent upon good document control systems and expensive because of the time commitments needed by participants to identify conflicts. When used as part of design coordination processes these error-checking functions mean that clashes can be avoided before the operations commence on site, removing potential delays associated with these clashes, again helping time predictability during the construction phase.

Additionally, BIM applications that allow for automated detection of spatial or proximity conflicts not only reveal building objects that permanently occupy the same location, but they can potentially be applied to identify process-clashes when entities temporarily occupy the same location. This helps planning task execution where multiple trades need to access the same workspace at closely related intervals. This is identified as an area to be improved in construction planning (Winch and North, 2006), and application of virtual construction techniques could help optimise trade sequencing in this manner.

Virtual prototyping and virtual construction practices allow for improvements in site-based processes to be made, that directly affect construction planning and therefore time predictability. These include: buildability assessments and trade coordination for refining sequence and method; precise quantification of materials to aid task duration planning; and modelling of on-site logistical operations. Again, these benefits can only be realised if the relevant information has been provided in the model for re-use. When planning the production of a BIM, it is necessary to consider what information is required, by which participants, and when they will require it. Researchers (Hardin, 2009; Eastman *et al*., 2011; Love *et al*., 2014) note that contractors, as opposed to designers, may develop their own BIMs from 2D design documentation. These may be needed because of lack of initial models, or because any existing models are not shared, or shared models are not fit for purpose and do not contain the necessary information.

Eastman *et al*., (2011, p269) identify information that contractors want to be able to extract from a BIM. The below list that is presented as an 'ideal' scenario, but it is more usual for models to currently provide no more than the first item.

- **Product information** - an accurate 3D model from which typical design output about building components can be produced - views that are to be of no lesser quality than typical construction drawings. From this model, building component information (properties) and quantities can be extracted (see below)
- **Temporary works** - components should be modelled that are critical to construction planning and sequencing - including the likes of plant, scaffolding, formwork. These components should also contain accurate properties and information regarding their limits and capabilities.
- **Specifications** - in built information or links to text documents for every component that is to be built or purchased.
- **Performance and requirements data** - information should pertain to the building systems requirements and designed performance (structural loads, heating and cooling loads etc), and means of analysis should be provided.
- **Status of design and construction information** - relatable to each component throughout the design, procurement and installation/testing periods.

Product data within a model can assist in the generation of material quantities, more accurately informing the calculation of construction programme task durations. Most BIM tools allow for basic automated counting of elements, areas, volumes, individual and sometimes cumulative object material quantities. The process of BIM-based design means that initial concept models are created which are populated with generic placeholder objects. These objects are swapped-out and upgraded to more detailed components over the course of various model development stages (see table 2.3). Earlier concept models only generate basic quantities (such as volume, area, item counts), but in more detailed models further information is able to be extracted. Use of product breakdown structures (PBS) informed by formats like SMM7/NRM ultimately allow full measures to be performed although more sophisticated quantification techniques may require the use of specialist BIM tools, plug-ins, or exporting to dedicated analysis tools.

Table 2.3: Model development Grade / LOD terminology (Alwan and Gledson, 2015)

AEC (UK)	AIA (US)	Name	Comments
Grade 0	LOD 100	Schematic	Massing model suitable for building shape and form. Areas and volumes extractable.
Grade 1	LOD 200	Concept	Generic modelling components introduced including wall, floor, column and beam objects.
Grade 2	LOD 300	Defined	Generic components substituted for manufacturer specific objects.
Grade 3	N/A	Rendered	Improvements in rendering and aesthetical purposes particularly 3D representations.
Grade 4	LOD 400	Fabrication	Fabrication and assemble information incorporated
Grade 5	LOD 500	Facility Management	As-built digital information suitable for operation and maintenance purposes

To increase predictability, data generated from the model can be fed into 4D BIM planning efforts that enable virtual construction process simulation so the executability of construction methods can be assessed in advance of action (Sulankivi, Makela, and Kiviniemi, 2009). Other objects including major plant and other temporary work items can be incorporated into this virtual construction environment and simulated in order to assess production performance.

During construction, careful management of the BIM to reduce product and process waste, can help avoid delays that arise from re-manufacture or re-work (Huang *et al*, 2009; Love *et al*., 2011). For suppliers of construction components there is now greater potential to exploit 'Design for Manufacture and Assembly' (DfMA) type processes by being able to re-use 3D object data exported from the model and direct importing such data for manufacturing purposes using computer numerically controlled (CNC) machines and Computer-aided design/computer-aided manufacturing (CAD/CAM) processes (Eastman *et al*., 2011; NBS, 2011; SCRI, 2011; Crotty, 2012). Such objects can be created from supplier-provided information and housed within free-to-access or subscription repositories. Use of these objects benefit designers during specification and improve error reduction in manufacturing, again, minimising the potential for delays when compared against traditional material manufacturing processes.

Quality Control can be assisted in a number of ways. During construction, Radio Frequency Identification (RFID) can be used for the tagging and tracking of components - particularly useful on projects that make use of off-site manufacture and storage, or those that embrace DfMA principles. Accuracy of installations can be verified through the use of laser scanning technologies for capturing as-built information (Tang, *et al.,* 2010; 2011; Huber, Adnan and Okorn, 2011), and Global Positioning System (GPS) technologies can be used for location verification (Bansal and Pal, 2009). All of these benefits can enhance construction processes and assist with project time predictability.

2.3.7 Barriers

There are however several barriers associated with BIM adoption that can negate the opportunities to improve time predictability. Bew and Underwood (2009) state that for an organisation to implement BIM it must be realistic relative to that organisations current capabilities. Barriers to the implementation of BIM innovation within, and across, organisations can be classified as a lack of e-readiness and openness to ICT innovations; issues associated with industry and organisational leadership and culture; commercial barriers (Sebastian, 2011), and legal and contractual concerns (Greenwood, Lewis, and Lockley, 2010). Barriers relating to people, process and technology (PPT) are the most frequently emphasised in the literature (Li, Lu and Huang, 2009; Sacks, *et al.,* 2010; Owen, *et al*., 2010; Hjelseth, 2010; Emmitt and Ruikar, 2013). Research undertaken by Rekola, Kojima and Mäkeläinen (2010) involved the use of a single case study project using BIM and Integrated Design and Delivery Solutions (IDDS) where data were collected from multiple sources including documentation, interviews and observations of process simulation. Inter-relationships between PPT factors were considered *"A problem was considered a people problem if it resulted from competence or knowledge problems, or related to collaboration or attitudes. Problems related to workflows, timing, procurement and contracts, or roles were categorised as process problems. Technology problems were mainly software originated"* (pp 268-269). Rekola, Kojima and Mäkeläinen (2010) noted the complex nature of PPT problems in that most items fall into more than one of each category (and offered several examples of such problems. The researchers noted that there were different approaches in solving these problems, but warned "*technology can be developed to adapt to the process, process can be developed to adapt to the technology or people can invent work-arounds concerning the technology or process problems. For example, people adapting to less than ideal processes is a short-term solution. In the longer term, to reach the pursued productivity rates and quality, the process should be fixed and technology improved to support it. In most cases, the fundamental solution requires taking into account all three aspects"* (Rekola, Kojima and Mäkeläinen, 2010, p270). Related research has identified that the implementation and success of BIM may stagnate due to issues associated with unsatisfactory technological interoperability, which can impede the flow of information through a project lifecycle (Grilo and Jardim-Goncalves, 2010; Stapleton *et al*., 2014).

2.3.8 Section Summary

So far, the study has identified concerns over the low rate of innovation in construction and explored aspects of construction planning that contribute toward the time predictability problem. This section further contributed toward **Research Objective 2** by analysing the planning of construction projects within the context of poor industry time predictability. This was done by focusing on how poor-quality production information contributes to this problem and discussed problems with existing information management processes. BIM was introduced, its potential for improving the quality of production information was discussed, and AEC industry resistance to technological innovation was expanded upon. Some of the benefits of BIM associated with improving time predictability were identified. The final section of the literature expands on 4D BIM as an innovation that can further assist the construction planning process with its potential for improving time predictability.

2.4 New approaches for Construction Planning using 4D BIM

Earlier sections of the literature review discussed the function and role of construction planning, considered the impact of complexity and uncertainty, and outlined the development of construction planning techniques. The individual stages of the planning process were identified, and the varying formats of plans considered. Criticisms of the planning process were presented, including: how conventional planning relies on the experience and intuition of the individuals; that plan presentation fails to communicate spatial and locational aspects of the construction sequence; and that formats used to communicate the process (the plan) have been independent from the product (building design). Potential improvements offered by BIM were then discussed, particularly: improvements in the quality of production information; user comprehension; and opportunities for virtual prototyping and articulation of construction information requirements. All of which can further improve project delivery and tackle the problem of poor construction project time predictability. 4D BIM is acknowledged as a useful addition to construction planning methods as it produces construction process visualisations (Hartmann and Vossebeld, 2013) which enables better understanding (Heesom and Mahdjoubi, 2004; Wang *et al*., 2004) and decision making (Hartmann *et al*., 2008).

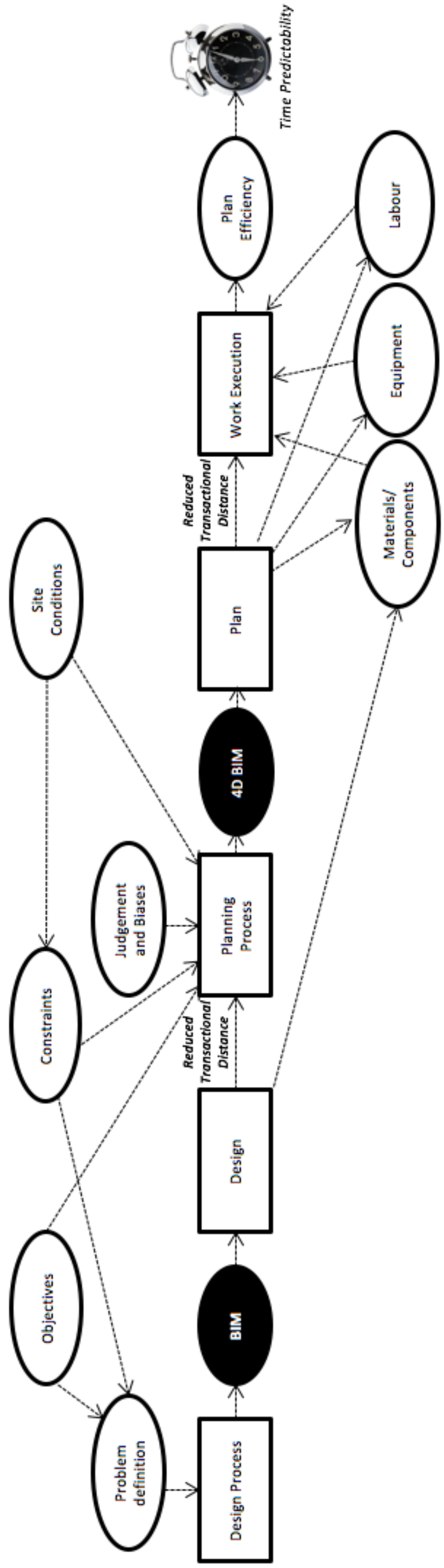

Figure 2.12: Determinants of Time Predictability using BIM and 4D BIM Innovations.

2.4.1 Definitions

Research has found that the use of 4D methods, where the dimension of time is linked to the 3D-model ($x + y + z + t$) are a good alternative to traditional forms of project scheduling (Koo and Fischer, 2000). Trebbe, Hartmann and Dorée, (2015, p83) explain 4D as "*… software technology that uses 3D representations of the existing conditions at a construction site, 3D representations of the proposed design that transform these existing conditions …* [and] *…allow[s] for the integration of the different construction designs and schedules…* [which] *…allows for three dimensional representation of when and where physical objects are planned to be built or demolished."* 4D methods have been referred to in a variety of ways in the literature, as evidenced within Table 2.4.

Table 2.4 - Various 4D naming conventions used in literature

Terminological variety	**Associated literature**
4D CAD	Koo and Fischer (2000); Liston, Fischer and Winograd (2001); de Vries and Harink (2007); Büchmann-Slorup and Andersson (2010); Mahalingam, Kashyap, and Mahajan (2010); Hartmann, Gao, and Fischer (2008); Trebbe, Hartmann and Dorée (2015)
4D Modelling	Büchmann-Slorup and Andersson (2010)
4D Planning and Scheduling (4D-PS)	Rischmoller and Alarcón (2002)
4D Simulation	Heesom and Mahdjoubi (2002); Tulke, and Hanff (2007)
4D Site Management Model (4DSMM)	Chau, Anson, Zhang (2005); Chau, Anson, De Saram (2005)
4D Technology	Wang, Zhang, Chau, and Anson (2004); Staub-French and Khanzode (2007); Hu, Zhang and Deng (2008)
Product Model and Fourth Dimension (PM4D)	Fischer and Kam (2002)

Whilst many of these terms have similar definitions, 4D planning involves making use of BIM to improve construction planning techniques. 4D planning is when a time schedule is linked to a 3D-model to enable visualisation of the time and spatial relationship of construction activities (Liston, Fischer and Winograd, 2001; Heesom and Mahdjoubi, 2002; Chau, Anson, Zhang, 2003; Büchmann-Slorup and Andersson, 2010) to analyse the construction schedule to assess its ability to be executed (Koo and Fischer, 2000), and help reduce scheduling errors through plan interrogation and validation, a process which consequently also improves communication between project team members (Tulke, and Hanff, 2007). 4D BIM can be regarded as an innovation when reflecting on the definitions of innovation previously examined earlier in the work (see Rogers, 2003; Hosseini *et al*., 2015) as it is a new practice that offering non trivial process-improvements to the planning of construction projects.

2.4.2 Improving communication of the construction plan through 4D BIM

Effective communication is a significant factor in any successful project (Gorse and Emmitt, 2007; 2009) Communication involves iterative processes that contain multiple components set against a background of 'noise' (Emmitt, 2010). These components include: the message itself and any necessary coding of the message; the senders; receivers; channels of communication; and some form of feedback to identify communication comprehension. Although the sender can be fairly certain that they have sent a clear message there will always be doubts whether the message has been received and processed as intended. Within the literature various communication models have been developed including early simple linear Sender-Message-Channel-Receiver models (Shannon and Weaver, 1949; Berlo, 1960) and later Encode-Transmit-Receive-Decode, transactional models of communication (Barnlund, 2008) that recognised the importance of coding/de-coding; communication noise, and feedback to test comprehension. Communication effectiveness relies on the success of closing the *transactional distance* between parties. This is depicted in Figure 2.13, and is defined as being the psychological distance that exists between people when communicating (Barrett, 2002 as cited by Soetanto *et al*., 2014).

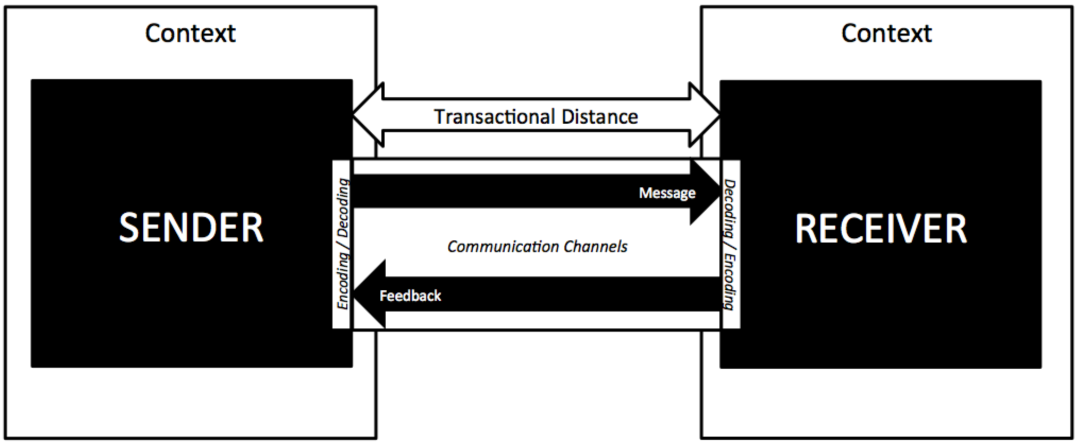

Figure 2.13: Transactional distance in communication.

The theory of transactional distance was developed by Moore (1993) as an educational theory addressing the exchanges and separations between tutor and student. All forms of construction production information – drawings, specifications, schedules etc., have been originated by someone who is attempting to communicate their own message. Often the receiver of production information can struggle to understand exactly what has been updated, or what is communicated (Marshall-Ponting and Aouad, 2005; Li *et al*., 2011) Construction planners use various formats to communicate their own message, i.e. the plan. Such media has historically included, marked up drawings, schedules, site layout plans and the programme (Laufer *et al*., 1994). Hartmann and Vossebeld (2013) have identified the need for greater clarity when facilitating communication about complex construction processes. 4D BIM innovation aims to amplify the understanding of the construction plan through 4D visualisations which are *“simpler representations of the development of the project and can be used by a* *wider variety of project participants at varying levels of skills and experience"* (Mahalingam, Kashyap and Mahajan, 2010, p148).

2.4.3 Origins of 4D BIM Innovation

The origins of 4D can be traced back to 1986/87 both to a collaboration between Bechtel and Hitachi Ltd (Rischmoller and Alarcón, 2002), and to the work of Martin Fischer and associated researchers from The Center for Integrated Facility Engineering (CIFE) at Stanford University, who created the original technique for producing visual 4D models (Fischer and Kam, 2002; Dawood and Mallasi, 2006). Over time, technology has advanced so where earlier technology simply made use of 3D *'dumb'* design in design software and allowed for the incorporation of time associations, now dedicated BIM management or analysis tools, enable the incorporation of multiple models, and schedule data (Trebbe, Hartmann and Dorée, 2015) to link intelligent objects to individual resource loaded and logic linked activities - a process described below. As early as 1996, the literature was discussing the possibility of automatic generation of construction activities directly from a dynamically linked design model (Fischer and Aalami, 1996) and the possibilities for re-use of data within a single project, as it was recognised that data relating to the planning of construction projects, methods, activity durations are not captured and stored for re-use. This was a concern of Fischer and Aalami, (1996). They envisaged the opportunities for intra-company knowledge transfer to subsequent projects, and augmented training of members of staff who were less experienced in construction planning.

2.4.4 Benefits and primary uses

Several functions of the planning process are improved through the use of 4D methods, including the abilities to gather information from a coordinated project information repository; improvements in the ability to identify activities through model interrogation; and to improve calculation of durations using automated quantity extraction processes (Hartmann, Gao, and Fischer, 2008). These improved abilities then enable the planner to produce more rigorous schedules (Heesom and Mahdjoubi, 2004) and more effectively communicate aspects of the plan (Hartmann and Fischer, 2007). This includes construction methods and sequence, directing the plan recipient toward the exact location of work content, and the impacts of resource movement and site logistics (Chau, Anson, and Zhang, 2004). Hazardous activities can also be interrogated to a greater degree (Sulankivi *et al*., 2009; Zhang *et al*., 2013; Zhou, Ding and Chen, 2013). Hartmann, Gao and Fischer, (2008) aggregated the results of 26 case studies to demonstrate a full range of 4D functionalities including the ability to produce photorealistic rendering of designs; design review and interrogation possibilities; cost estimation functions; analysis of design and construction options. They also discussed how these areas could be useful to construction project management professionals. Despite this range of functionality these researchers found that that different practitioners typically used only one area of application specific to their individual requirements, and that the area of 4D BIM innovation most frequently used was *"to review the integrity of schedules and construction sequences, to evaluate time–space conflicts, site accessibility, trade coordination, temporal structures, lay-down area use, or different construction methods or means"* (p781).

Mahalingam, Kashyap, and Mahajan (2010) also noted that in the DCP stages the greatest benefits were in the assessment of planned construction methods and in undertaking analysis of the alternatives, as well as in detecting conflicts and clashes. Major benefits during PBP and PCP stages include the communication of construction plans and processes to project stakeholders, (Liston, Fischer and Winograd, 2001; Dawood, 2010; Mahalingam, Kashyap, and Mahajan, 2010) These improvements in communication efficiency that 4D offer over traditional forms of production information have been explored by several researchers. Rad and Khosrowshahi (1997) advised that 3D visualisations have helped close a communication gap between designers and end recipients of information such as clients and contractors whilst Heesom and Mahdjoubi, (2004) noted that the use of 4D allows this gap to narrow even further by enabling project participants to understand the sequence of construction and progress made at specific points in time. Some researchers have looked at how to measure improvements in communication efficiency. Efficiencies in communication were investigated by Liston, Fischer and Winograd (2001) who reported that within a R&D project approximately 50% of the time in construction project meetings, use was made of 4D to help explain crystallise design intent, whilst a further 20% of the time 4D BIM innovation was employed to assist in explaining construction operations and communicating the content of work packages. These gains can be contrasted against research into the development of 4D performance indicators which noted from observations of project case studies, that an average of 30% reduction in project meeting time was saved through the use of 4D BIM against comparable project team meetings that had not used this innovation (Dawood, 2010). Other identified planning related benefits of 4D BIM include more effective coordination and review practices (Hartmann and Fischer, 2007; Olde Scholtenhuis *et al*., 2016), better planning and management of on-site space and resources (Kassem *et al*., 2015; Wang *et al*., 2004), and use of automated construction progress tracking capabilities (Kim, Kim and Kim, 2013; Kim *et al*., 2013).

2.4.5 Process of creating a 4D model

4D BIM can be considered to be a modular technological process-based innovation. Chau, Anson, and Zhang (2003) identified the *inputs* necessary for 4D model, shown in Figure 2.14.

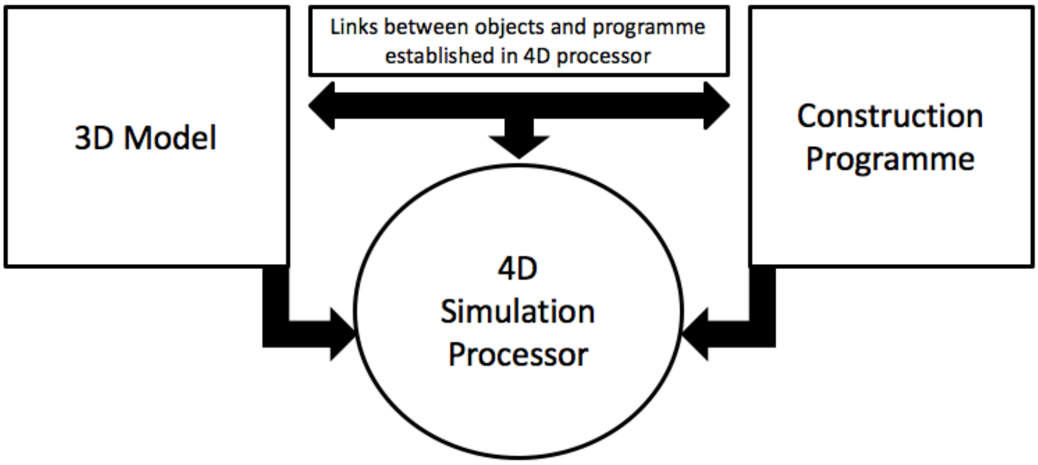

Figure 2.14: 4D Simulation Processor

These include:

- A 3D geometric model: where graphical objects are categorised as either: building components (structural elements); operational objects (direct process objects - concrete pump, scaffold etc); and temporary facilities (those objects that support the enabling of construction such as welfare units, material storage areas etc);
- The construction programme: which contains activity data, durations, and logical relationships etc.
- The central processor: the 4D simulation tool that allows the linking of the 3D model and the programme data to occur. Current examples of such a processor would include Autodesk Navisworks, Synchro, VICO and XC Builder.

Tulke and Hanff (2007) describe the process of importing and linking the separate 3D model and programme data into a central software package model. This is done to establish links between the activities (represented as bars, both in its native application, and again in the central processor) and the graphical objects, and to define the visual parameters - how and when the object will appear in a 4D simulation. They also consider several associated issues with this process. The first of which is that adjustments in the granularity of detail in either the object or the detail on the bar chart may be necessary. A common example of this would be a floor slab modelled as a monolithic object, without construction joints, where in reality, the construction team may need to split the slab down into several separate pour zones. In this example, conversations would be needed about the remodelling or re-planning of an object or sequence of activities. The second issue is that several process revisions may be necessary to realise the ideal quality. Adaptions of the programme may have to be made, and re-importing of model and programme data into the processor and relinking tasks to the objects may have to occur. Whilst some 4D applications offer opportunities to establish automated or semi-automated linking between task and object many packages require the links to be manually established - both initially and then for any subsequent revisions. This is a process that can involve substantial time and effort, particularly when considering the complexity of the many thousands of ‘Tasks Per Programme’ (TPP) and associated logic links. A third issue is that as the preparation of the 4D simulation occurs after the creation of the model(s) and the programme of works, additional time needs to be allowed for in the PCP process - both in the initial preparation and for any re-planning works necessary. A further consideration revolves around who should control the 4D simulation software to undertake the linking. Whilst some contractors are investing in BIM and 4D technology - it is not difficult to imagine that designers more familiar with

3D modelling tools may be requested to perform the links - thus putting designers in control of the 4D schedule, and ultimately in control of communication of the construction plan.

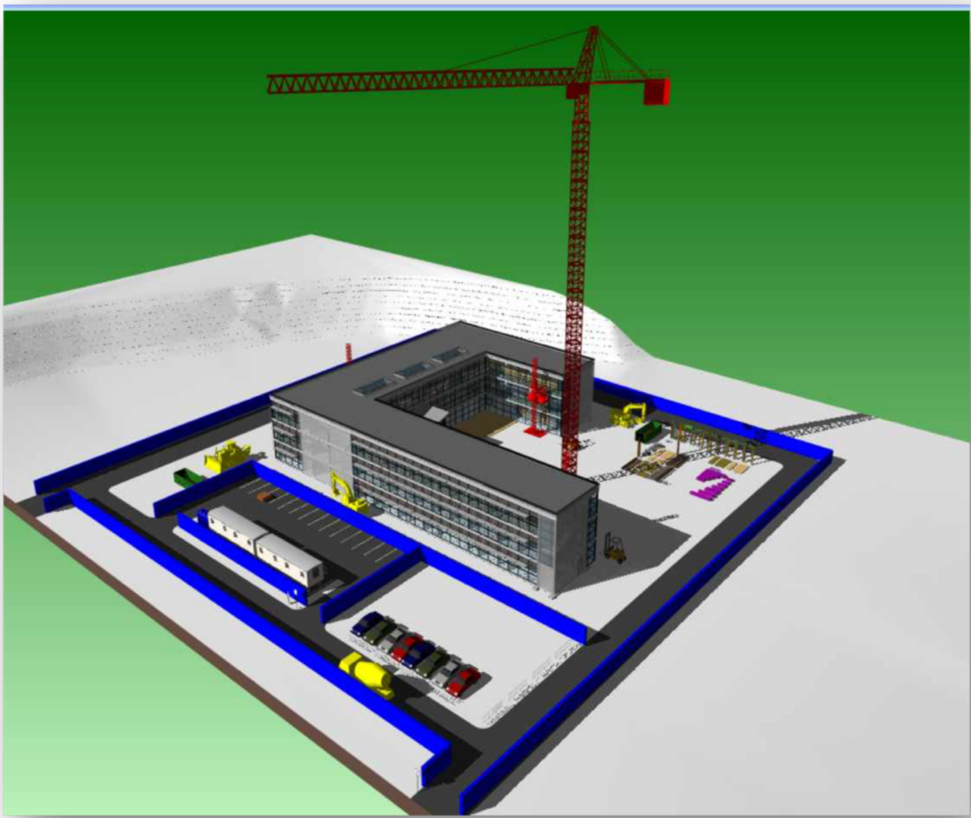

Figure 2.15: 4D planning output. Researchers own (2013).

2.4.6 Problems of resistance and diffusion

Several researchers consider there to be an increase in the uptake of construction professionals using 4D methods (Hartmann, and Fischer, 2007; Hartmann, Gao, and Fischer, 2008; Trebbe, Hartmann and Dorée, 2015). Mahalingam, Kashyap, and Mahajan (2010), however have noted a gap between the communication and operational benefits espoused within the literature, and 4D use within industry. They note that because of the practical difficulties of implementing 4D BIM, there is a need to further explore implementation, and the perceptions of intended users towards this innovation. Organisational and project-related barriers have impeded the widespread diffusion of 4D BIM and despite the apparent advantages afforded, any misunderstanding by planners and construction practitioners can cause problems, as there may be human resistance to such innovation (Li *et al.*, 2008). For many experienced practitioners, any time a change to working process is introduced, particularly in having to learn new software, it can be frustrating. Professionals such as construction planners are likely to strongly identify themselves by the professional and technical expertise skills that they have acquired over a long time, and Dodgson and Gann (2010, 16) identify that such disruptive innovations are likely to disturb a delicate balance and implicit social contracts between organisations and their employees. Mahalingam, Kashyap, and Mahajan (2010) also warn that despite these benefits the innovation *“might not diffuse through the construction industry unless 4D modelling and analysis is integrated into existing project planning approaches”* (p148). Thus, there is then a need to consider 4D BIM from the perspective of established innovation diffusion theory.

2.5 Chapter Summary

The literature review chapter has helped provide necessary context for the thesis. The twin problems of poor time predictability of construction projects and the diffusion of construction innovations were considered, and a number of key sub-themes were explored regarding these matters. Focused use of the literature has addressed the first two research objectives:

- Examine classic innovation diffusion theory and its applicability to the construction industry.
- Analyse the planning of construction projects within the context of poor industry time predictability.

A need for further empirical research into construction industry innovations is apparent, and an argument has been made for a study of the diffusion of 4D BIM making use of classic innovation diffusion theory. The next chapter details the research philosophy and approach undertaken in such work.

Chapter Endnotes

[i] Emmitt (1997) previously considered the applicability of IDT to the UK construction industry and focused specifically on the innovation-diffusion process, by looking at the decisions made in the adoption or rejection of innovative building products. Emmitt contributed to diffusion theory by proposing two additional stages necessary for any innovation-decision process specific to the diffusion of innovative building products (*3A tender action* and *4A specification substitution*) and advised of the intentional and unintentional 'gatekeeping mechanisms' deployed by managers of architectural practices who control the level and flow of information, thus make it ultimately more difficult for building product innovations to be adopted. Emmitt's work also proposed the notion of *postponed adoption*, where an innovation is not immediately adopted or rejected but knowledge of the innovation is retained for purposes of future application.

[ii] Larsen (2005a) stressed the low levels of trust and hyper sensitivity to risk within the UK construction industry, and emphasised the importance of informal communication channels or 'networks' within the innovation diffusion process. Having an epistemology of social realism, Larsen (2005a) argues that the diffusion of innovations is strongly influenced by the iterative interactions between actors, their social system and the innovation itself. Larsen's work (Larsen, 2005b; Larsen and Ballal, 2005; Larsen, 2011) built upon existing sociological diffusion concepts (*cohesion*, *structural equivalence* and *thresholds*), stresses the importance of cohesion and introduces the concept of a *Personal Awareness Threshold*.

[iii] The views of Koskela were reinforced by Ballard and Howell (1997; 1998a) who supported the need for a new production philosophy in construction, and confirmed that in the 'Lean Construction' movement, a focus should be upon the management of flow, and the reduction of waste. Ballard and Howell (1998b), also further built upon the work of Koskela, by attempting to position the uniqueness of construction. They suggested that construction does not possesses a singular unique defining property, but instead its uniqueness is a result of a combination of two characteristics - 'fixed position manufacturing' (the assembly of parts into a whole) and the individual location of each construction project (what they called the 'rooted-in-place' nature). This latter element brings various challenges in terms of its environmental and climatic conditions, such as the site-specific ground conditions, the ease of supply of particular building materials (both of which will impact upon technology selections), and the requirement to meet exacting legislation, such as national building regulations

etc., all of which can impact upon the project. Ballard and Howell (1998b) note that construction is essentially the design and assembly of objects that are fixed-in-place, and it has sizeable challenges because of the vagaries of the site production processes, and the challenges of making unique products, with temporary project teams.

[iv] Optimism bias applies equally to cost as well as time estimates, although the planning fallacy usually relates to time estimates. Notable large-scale construction projects that have suffered from aspects of optimism bias in cost estimation have included the Sydney Opera House (an overrun of 1,400% as described extensively by Bent Flyvberg in his research including Flyvbjerg, 2005; 2008; 2014 and Flyvbjerg, Garbuio and Lovallo, 2009) and the Scottish Parliament building (an overrun of 1,600% as described by Kahneman, 2011). Subsequently it has been mandated by HM Treasury that corrective prescription now occurs during the process of investment appraisal, which resulted in an increase in the calculated budget for the London Olympics 2012 project (Winch, 2009).

Chapter 3: Research discussion, philosophy and approach

The purpose of this chapter is to outline how the research has been undertaken and to make explicit the rationale for doing so. This section first explores classic research paradigms, and discusses the conventional research paradigms and dominant research methods within the Construction Management field. Use has then been made of the 'Research Onion' (Saunders, Lewis and Thornhill, 2009) as this model provides a suitable medium in which to illustrate how the actual research inquiry has been shaped and is useful for the structuring of the remainder of this section. This model provides a systematic way of identifying the research philosophy, indicating how the research was carried out, and allowing a structured manner of discussing the appropriate research approaches and the selected data collection strategies used to meet the objectives of this project.

3.1 Research discussion

All research can be categorised somewhere on the spectrum between ‘pure’ and ‘applied’ research. Pure research is ‘theoretical’ and undertaken to develop knowledge and assist in the search for ‘truth’, whereas applied research makes use of the pre-existing scientific knowledge accrued through pure research, usually in industrial environments, to help tackle or solve a practical problem (Fellows and Liu, 2008). Equally, contributions toward pure research can often be realised as a by-product of the findings from the process of applied research. The idea of this spectrum is useful but in reality, much research can be complimentary and contribute to both the pure and applied domains, and depending upon its purpose, can both advance existing theory and contribute toward solving a practical problem. In this instance, the problem at hand - the poor time predictability of construction projects - is indeed both a practical problem, and a 'wicked problem' (Churchman, 1967; Winch, 2010).

3.1.1 Classic research paradigms

Fellows and Liu (2008) define a *paradigm*[i] as a lens - the theoretical framework influencing a system - through which events are viewed. Paradigms determine 'what' is to be viewed (a research event) and 'how' such an event is to be explored. Results are always considered in context against the existing paradigm parameters - similarities through verification or differences through explanation. Existing knowledge advances incrementally, generally through slow evolution with expected results adding confidence to existing research paradigms. Occasionally results do not fit the anticipated patterns or existing theory, and through new lenses or perspectives, explanations are generated that can lead to revision or revolution of existing scientific knowledge, known as a 'paradigm shift' (Easterby-Smith, Thorpe and Jackson, 2008, pp 57-58).

Construction management draws from both the natural and social sciences and the contrasting paradigms in this domain are often presented as being in opposition, competing for methodological sovereignty (Dainty, 2008). These competing 'classic' paradigms are classified as 'positivism' and 'interpretivism' (Fellows and Liu, 2008). Several researchers both within construction-related and wider management research literature use social or natural science conventions, or variations upon these, such as 'functionalism' (Fellows and Liu, 2012; 2013) or 'objectivism' (Saunders, Lewis and Thornhill, 2009), for a positivist approach and 'social constructionism' (Easterby-Smith, Thorpe and Jackson, 2008); 'constructivism', 'naturalism' (Robson, 2002), or 'subjectivism' (Saunders, Lewis and Thornhill, 2009) for more interpretivist approaches. Many of these approaches are subtle in their distinctions but it is outside the scope of this work to explore these. In this work, the researcher will generally adhere to orthodox positivist and interpretivist naming conventions as used within much of the Construction Management literature. Natural and social sciences also have their own competing philosophical assumptions on the nature of reality - *ontologies*. In natural science, these are between ‘realism’ and ‘relativism’, and in social science, the positions are between ‘representationalism’, ‘relativism’ (or ‘critical realism’) and ‘nominalism’. Ontologies remain generally fixed personal philosophical positions (Runeson and Skitmore, 2008), whereas *epistemologies* are fluid and involve the relationship between the researcher and the research subject matter i.e. considering an appropriate way of tackling a problem at hand given a particular researchers ontology. Epistemology affects methodology - research strategy or principles, which in turn affects the method and the selection of individual research techniques.

All research requires the collection and analysis of data. Hart (2005) explains that data is whatever is considered necessary to address research objectives and questions. He offers extensive examples of data (p356) – which includes statistics, interviews, questionnaire responses, and much more – then advises that data is “*what people produce (artefacts), what they do (actions/behaviours) and how they do what they do with the things they produce, which include beliefs, attitudes, opinions, customs, science and culture*”. Three approaches exist that facilitate the collection and analysis of data: quantitative, qualitative, and mixed-methods research (Creswell, 2014). Quantitative research involves the collection of numerical data (or, more precisely, data that can be expressed numerically), which can be measured on research instruments, then analysed using conventional, standardised statistical procedures (Easterby-Smith, Thorpe and Jackson, 2008; Creswell, 2014). This is usually done to establish, or study for, any relationships between variables. In contrast, qualitative research usually involves the collection and analysis of non-numerical data, most typically words (but other examples include images, photographs, videos etc.), which are interpreted for insight and meaning. "*Analyses of such [qualitative] data tends to be considerably more difficult than with quantitative data, often requiring a lot of filtering, sorting and other 'manipulations' to make them suitable for analytic techniques*" (Fellows and Liu, 2008). Mixed-method research efforts, such as this work, provide opportunities to incorporate and combine multiple approaches within the same project, and there are numerous ways in which this can be achieved (Johnson and Onwuegbuzie, 2004; Johnson, Onwuegbuzie and Turner, 2007; Bryman, 2012; Creswell, 2014). The more usual research strategies that can be employed within any research approach include 'Action', 'Ethnography', 'Survey', 'Case Study' and 'Experimental' approaches (Fellows and Liu, 2008; Yin, 2009), and Saunders et al., (2009) also lists 'Archival', and 'Grounded Theory' research styles (note that the selected survey and case study strategies used within this mixed-methods research project are more fully detailed later in this chapter). Whatever style is selected, data can be captured using a range of approaches including the likes of participant observations, in-depth interviews, questionnaire surveys, or document analysis (Hart, 2005; Fellows and Liu, 2008).

Returning to the primary research paradigms within the construction management domain, the following definitions are used for the purposes of this work. Positivism is an approach that *"recognises only non-metaphysical facts and observable phenomena, and is closely related to rationalism, empiricism and objectivity"* (Fellows and Liu, 2008, p17). Positivism is closely aligned with the natural sciences where researchers view reality as an external construct that can be measured objectively. Positivism is heavily associated with quantitative research. Other key features of positivism are that observers should be independent (non-participatory) in any study. Attempts to demonstrate causal explanations are a key aim, although it is usual that correlations are often found or proved. Research processes involve hypothesis then deduction about the types of observations that will yield data that can support or reject a hypothesis; and to do this, problems should be reduced down to their simplest elements - units of analysis - a process known as reductionism.

Interpretivism refutes the idea that the researcher can be independent or neutral from the reality of the research subject. Davies (2007, p238) argues that *"all knowledge is relative to the person interpreting it"*. Herein lies a risk that the researcher must seek to ensure that a continual checking of the gathered evidence occurs so that it may be reviewed against existing theoretical models or against any proposed theoretical advances made by the researcher. If positivism is concerned with explanation (i.e. 'casual'), then in contrast, the interpretivist paradigm deals with aspects of understanding or 'sense-making' of human behaviour (Bryman and Bell, 2003 as cited in Dainty, 2008). Interpretivism deals with the *"empathetic comprehension of human action rather than the forces which shape it"* (Dainty, 2008) It aims to explain the social construct of 'truth' from an individual perspective, collectively, from groups of people, indeed, as explained by Fellows and Liu (2013, p401), interpretivism has long been the dominant paradigm in studies of culture, *"Interpretivism gives a perspective on how groups of people develop a common sense of history, values, beliefs, and purpose through collective interpretations which, then, act to produce the emerging social institutions laboratory of their existence"*.

3.1.2 The dominant research methods in Construction Management

Knight and Turnbull (2008, pp72-73) acknowledge a basic problem with Built Environment research, that it "*is clearly not a discrete discipline with its own standard approaches to philosophy, methodology and methods*". Aside from epistemological concerns, the predominant research methods used in construction have been listed as "*surveys, interviews, simulation and stochastic modelling, participant observation and laboratory experiments"* (Fellows and Liu, 2008, pp87-88). These researchers then adapted the work of Remenyi *et al* (1998), to categorise, and make distinct, different types of empirical design and their research approaches. They acknowledge that these same methods which are categorised as highly positivistic, also have room for interpretation. Highly interpretivist methods include participant observation, and in-depth surveys which use interviews. They also note that case studies have the scope to be either a positivist or interpretivist research method.

An investigation into the various methodological preferences in construction management research was conducted by Dainty (2008) who outlined a philosophical debate held in the journal Construction Management and Economics (CM&E), in the mid-1990's and then undertook a review of all 107 papers published in a complete volume of the journal (Volume 24, 2006). The research was instigated following published discussions between researchers after the publication of a review of the first ten years of CM&E (Betts and Lansley, 1993). It records how David Seymour and others (Seymour and Rooke, 1995; Seymour, Crook and Rooke, 1997; 1998, all as cited in Dainty 2008) questioned the dominance of the positivist approach within the community. This was countered by authors such as Runeson (1997) and Harriss (1998). In the review a cross sectional analysis of CM&E output from volume 24 was undertaken. It was found that 71% of papers employed quantitative methods (indicating a positivist approach), 8.4% employed qualitative only methods (indicating an interpretivist approach) with mixed methods having a larger percentage share of 11.2%. The remaining 9.4% was made up of reviews and other types of papers. From the qualitative and mixed-method approaches by far the dominant research method was individual open-ended interviews which accounted for 64% of the methods employed. Dainty (2008) found that there had been ‘narrowness’ in the research outlook of a community, *“firmly rooted within the positivists traditions”* (p10), and that what qualitative methodologies had been employed suffered from an over reliance on open-ended interviews in the method selection. Dainty (2008, pp10-11) advocated methodological pluralism - the combination of methodologies to gain the benefits of holism, richer insights and more complete understanding - in Construction Management research. Fellows (2010, pp10-11) concurred that the dominant paradigm adopted in the approach to Built Environment research had been of a positivistic ‘hard’ quantitative nature but believed that a shift had begun toward interpretivist ‘soft’ research, indicative of a constructivist paradigm had begun and it was likely that the use of multi-methodology approaches would increase. Pluralism, emerging from the use of triangulation would do more to generate a “*holistic paradigm involving integration of previously individual paradigms, and their adopted methods of investigation, into a more complex, and, arguably, realistic view*”. This project makes use of such methodological pluralism, discussed below immediately after identification of the population of interest and the sampling strategy employed.

3.2 Issues of population and sampling

The population of interest for this study was those UK construction sector organisations looking to innovate by incorporating BIM and 4D BIM within their project delivery practices. Relevant individuals (primarily construction planners and project managers) who represent such organisations were the focus of the various data collection strategies employed across this multi-stage project. These were accessed through convenience and purposive sampling strategies. It should be noted that there are difficulties in quantifying such a population. For example, as previously identified Myers’ (2013) determines that 1,650,000 professionals are directly involved in the delivery of construction projects, a figure which also includes professional design and managerial consultants. Membership levels of relevant Professional Institutes also provide useful indicators. Answering a request for information, the CIOB provided confirmation that as of 1st February 2017 it had 36,193 UK Members (all grades), whereas the APM advertises that it has over 22,000 individual members in the UK Of course, there are more practitioners than chartered members, and not all chartered members perform project management and planning roles. Nonetheless such a population can be assumed to be in the tens of thousands[1].

3.3 Research philosophy and decisions

Figure 3.1 illustrates the ‘research onion’ model, which is used to guide the reader in understanding the research decisions taken in this project. The below discussion provides detail of the philosophy, approaches, strategies, choices and time horizons selected. Information about how the data were collected and analysed occurs within subsequent chapters which provide detail on the individual phases in this multi-stage, mixed-method research project.

1 An alternative approach is to consider the population size at organizational level. Relevant data here reveals that out of 273,775 related ‘construction’ businesses, 65,443 are registered contractors in the UK industry (ONS, 2016), with only 257 of them employing 300 more people (about 0.001% of the firms in the industry). However, there is no way of determining how many of these firms are actively looking to innovate in their approach to project delivery.

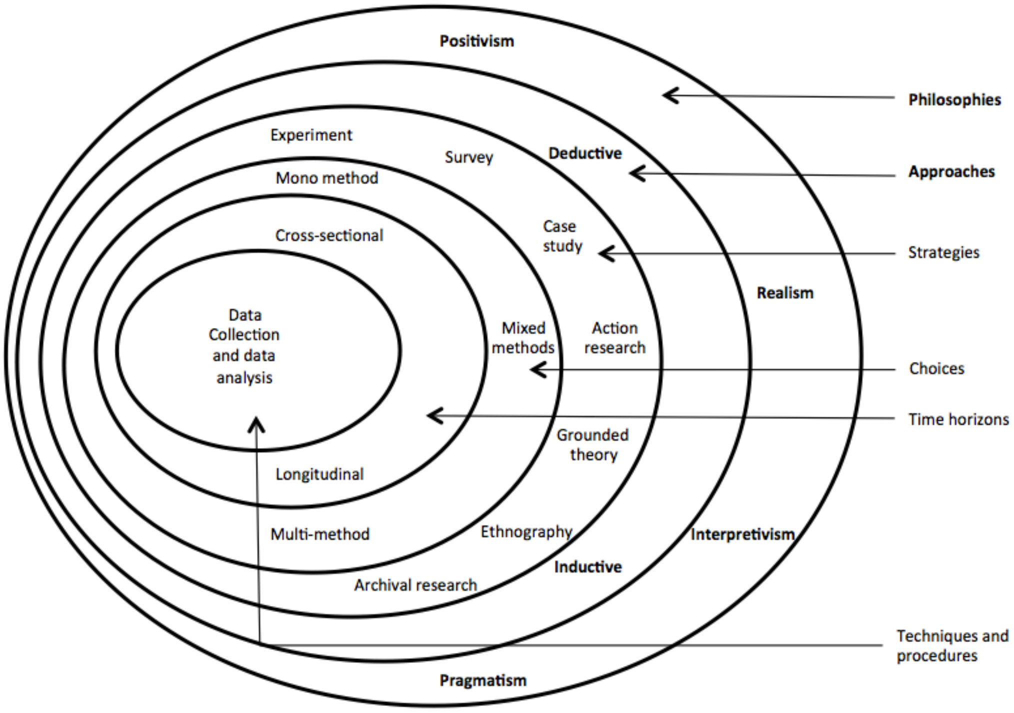

Figure 3.1: Research Onion. Reproduced from Saunders, Lewis and Thornhill, 2009, p108)

Guba and Lincoln (1994, as cited in Saunders, Lewis and Thornhill, 2009) state that issues of research methods are of secondary importance to questions of paradigm. The preceding discussion about the dominant and emerging paradigms in construction management research did not completely cover all available philosophies. In addition to classic positivism and interpretivism philosophies, several management researchers (Robson, 2002; Easterby-Smith, Thorpe and Jackson, 2008; Saunders, Lewis and Thornhill, 2009) have all included other philosophies known as ‘pragmatism’ and ‘realism’. The researcher has long struggled with the view that one must hold a fixed philosophical position and that a side must be chosen between the positivists view of the external nature of reality and the interpretivist view that reality is socially constructed.

The first alternative to the positivism/interpretivism paradigms is the philosophy of ‘realism’, although the scientific approach to the gathering and understanding of evidence is somewhat similar to positivism. Robson (2002, p29) states that "*realism can provide a model of scientific explanation which avoids both positivism and relativism*." Realism states that reality is external, objects exist independently of our knowledge and experience of them, (Saunders, Lewis and Thornhill, 2009) and is used in the natural and social sciences, particularly for matters of evaluation research. Saunders, Lewis and Thornhill, (2009) also defines direct (also known as 'naive') realism - as 'what you see is what you get' in the relationship between object and observer and contrasts this with the critical realism. This is where there is an observation in the first instance then the processing of that observation within the observer in order to interpret reality and construct meaning. Robson (2002, pp41–42) is a social researcher who is critical of both positivism (which he declares as having been discredited) and of what he considers to be the unscientific nature of the relativist (read interpretivist) approaches, proposes critical realism as the way forward from a critical social science perspective and advises of several other strands of realism are available including 'scientific', 'critical', 'subtle' and 'transcendental' forms of realism.

A further alternative is the 'pragmatist' philosophy, and this 'non-purist' position is the most appealing philosophy, the one which the researcher subscribes to, and best describes the approach which has informed this work. A pragmatist philosophy holds that choosing between one or the other philosophies is unrealistic in practice, and the most important determinant of research approach are the research questions themselves (Saunders *et al.*, 2009). Morgan (2007, p72) identifies that, "*In a pragmatic approach, there is no problem with asserting both that there is a single 'real world' and that all individuals have their own unique interpretations of that world*". Pragmatism allows for the use of mixed methods research, often referred to as the third (or middle) research paradigm, to 'answer the question(s)'. Robson (2002) and Easterby-Smith, Thorpe and

Jackson (2008) note the compatibility and synthesis that the approach of pragmatism offers between the positivist and relativist approaches - and argue that that truth is 'what works'. Charles Sanders Peirce, William James, and John Dewey are frequently identified in the literature as the classical pragmatists, and Dewey noted the need to balance the 'concrete' and the 'abstract'; to equally reflect and to observe. Johnson and Onwuegbuzie (2004, p17) identify that the basic pragmatic maxim is "*choose the combination or mixture of methods and procedures that works best for answering your research questions*".

3.3.1 Research approach and hypotheses

The two main research approaches are those of deduction and induction. With deductive research, theory and hypothesis are developed from the literature and a research strategy is subsequently designed to test the hypothesis. Conversely with inductive research, data are collected and a theory is subsequently developed as a result of the data analysis. Again, these approaches are not mutually exclusive, as Saunders, Lewis and Thornhill explain: *"not only is it perfectly possible to combine deduction and induction within the same piece of research, but also in our experience it is often advantageous to do so*", (2009, p127). In this study, a broad hypothesis was formed:

"*If classic innovation diffusion theory can help explain 4D BIM adoption within UK construction planning practices, then a study of 4D BIM adoption can be undertaken in order to contribute to innovation diffusion theory".*

That allows an initial deductive research process to occur, which can then be followed by an inductive research process. The broadness of this hypothesis also means that a range of classic innovation diffusion variables could be used to determine the rate of adoption of 4D BIM adoption.

The study is deductive in that a ready theory can be generated from fields where there is a wealth of existing literature - in this case these fields are the areas of traditional construction planning (where the assumption is that traditional methods of construction planning result in poor time predictability) and innovation diffusion research. However, the study is also inductive by researching a topic where there was little existing literature - 4D BIM planning - which is an alternative planning method, to generate new data to analyse and formulate theory. So, throughout this multi-stage research project, an evolving relationship between existing theory and observation/findings means that an iterative research approach was adopted rather than a distinctly deductive approach of theory > observations/findings, or inductive approach of observations/findings > theory (Bryman, 2012, p27). It is also important to note that this iterative approach contributes towards satisfying the research objectives. Deductive tendencies assisted in the examination of classic innovation diffusion theory and its applicability to the construction industry (Research Objective 1), and in analysing the planning of construction projects within the context of poor industry time predictability (Research Objective 2). Inductive tendencies then assisted in an examination of the development of 4D BIM adoption in the UK construction industry (Research Objective 3). A deductive approach was necessary for investigating the diffusion of 4D BIM innovation within UK construction planning practice (Research Objective 4). The final research objective is concerned with using this study of 4D BIM to develop a model that further informs innovation diffusion theory (Research Objective 5), therefore an inductive approach was necessary.

3.3.2 Research purpose, strategy and choice

Fellows and Liu (2008) and Yin (2009) identify that research can be undertaken for exploratory, descriptive, or explanatory (causal, predictive) purposes, or it can include a combination of these (Saunders, Lewis and Thornhill, 2009). These categories are not concrete, because as Robson (2002) notes, the purpose of an enquiry is subject to change over the course of a study. Further categories of research include instrumental research or interpretative purposes. Fellows and Liu (2008) note that research can be further sub-categorised into aspects of either product, process or both, with Construction Management research efforts, such as this study, tending to be process-orientated research.

This research project includes elements of exploratory and explanatory research. There are broader exploratory elements that help satisfy Research Objective 3, whilst Research Objectives 4 and several of its sub-objectives (4.1–4.4) are satisfied through focussed explanatory research.

The research onion model illustrates the available strategies. This project had 246 research participants and multiple strategies were used[2]. A case study (Chapter 4) and a questionnaire survey (Chapter 5) proved useful in the preliminary exploratory part of the study, with both qualitative and quantitative analysis used where appropriate. During the latter explanatory stage of the project, survey research, through questionnaire (Chapter 7) and semi-structured interview methods (Chapter 8) were used. Specific details of the research design for each method used is provided in each of these chapters. However, to offer general insight, case study research and survey research are both now briefly introduced.

2 The schedule of all 246 research participants is provided in Appendix C.

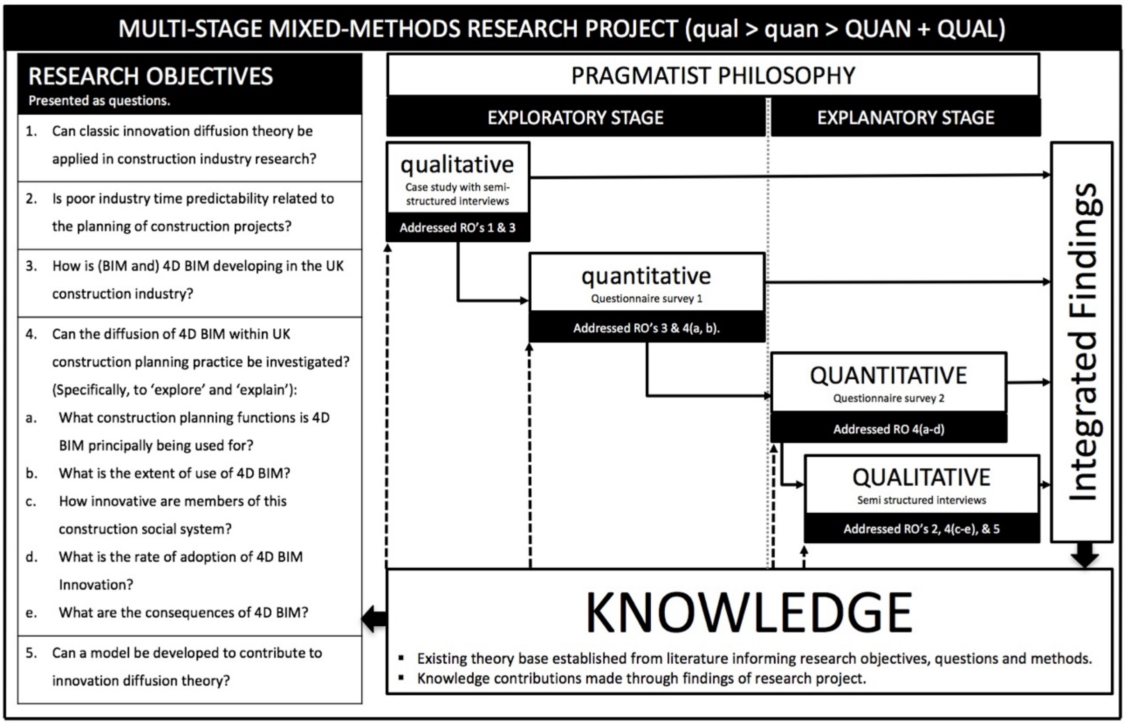

Figure 3.2: 'Road map' of research, showing how methodological approach is linked to research objectives.

Case studies are useful for purposes of in-depth data collection that serve 'exploratory', 'descriptive' and 'explanatory' purposes. The 'case' can be representative of the research subject, be a particular instance (Fellows and Liu, 2008), or focus on either a single, or a small number of individuals or entities such as organisations or events (Easterby-Smith *et al.*, 2008). Innovative or representative construction projects or aspects within construction projects would qualify as ideal case study material, indeed, Proverbs and Gameson (2008) recognise that case study research appears to be highly relevant to an industry that is project driven and made up of many different types of organisations and businesses. Case studies can be of individual or multiple instances and can either focus on key specific incidents, or be a more longitudinal study of the case over a period of time. Yin (2009) as the primary proponent of case study research, advocates that a linear, but iterative process, is used of *plan* > *design* >

prepare > *collect* > *analyse* > *share* to ensure validity and protect the method against criticism that the method can be unscientific. Easterby-Smith, Thorpe and Jackson (2008, p97) advise on the requirements for having a clear design prior to data collection requiring: *"the main questions or propositions, the unit of analysis, links between data and propositions, and procedures for interpretation of data".* Fellows and Liu (2008) advise that in the study of a production process such as a construction project, case studies often combine data from key participants with documentary data. In this study use is made of an exploratory case study investigating the consequences of a decision by a large contracting organisation to adopt the use of BIM across all of their future projects. Findings from this case study were published in the peer-reviewed journal article, '*Hybrid project delivery processes observed in constructor BIM innovation adoption'* (Gledson, 2016), with key details being reproduced in Chapter 4.

Surveys are a means of obtaining data from a representative sample of a population. These samples are commonly surveyed through the use of interviews or questionnaires. Interviews can range from unstructured discussions, useful in exploratory research, to semi-structured interviews allowing researchers flexibility in the ordering, phrasing, and content, of questions up to full structured interviews, where the exact same phrasing and ordering of questions are used. Primarily, qualitative data are collected in interviews, though there is also scope for collecting quantitative data using these methods. Structured questionnaire surveys are useful to collect a large amount of data from a population in an economical and efficient manner. Primarily, quantitative data is collected using such surveys which can then be used for descriptive, or exploratory analysis, although similarly, qualitative data can also be collected using this method. Depending upon the quality of survey design, inferential analysis of the data collected can also be used to better understand the relationships between variables for purposes of explanatory research (Easterby-Smith, Thorpe and Jackson, 2008; Saunders, Lewis and Thornhill, 2009). Key concerns in any survey design include the relevant population and representative sample sizes and the rate of response to the survey. Two surveys were employed in this study. Firstly, during the exploratory stage of the study, use was made of an online questionnaire survey to partially address Research Objective 3 by investigating how contracting organisations have implemented and made use of 4D BIM and virtual construction in order to improve project delivery. Interim results of this research were published in the proceedings of the 30th annual ARCOM conference (Gledson and Greenwood, 2014), with final results being published in the peer-reviewed journal article: *Surveying the extent and use of 4D BIM in the UK* (Gledson and Greenwood, 2016) and the complete set of results are reported in Chapter 5. Secondly, a further survey was employed as part of the explanatory stage of research, the results are detailed in Chapter 7. Similarly, interim results from this research were published in the proceedings of the 31st annual ARCOM conference (Gledson, 2015) with the complete set of results are reported in this chapter. As part of the explanatory research stage, a final round of semi-structured interviews was undertaken concurrently with the second survey and the results of these interviews are detailed in Chapter 8, and again interim results of this research were published in the proceedings of the 32nd annual ARCOM conference (Gledson, 2016).[3]

In terms of *research choice* in this project, a mixed-method research choice has been made whereby sequential qualitative, quantitative, then concurrent quantitative and qualitative (qual > quan > QUAN + QUAL) data collection techniques and analysis procedures are used, but were not combined. Different

3 Appendix A provides details of all research output arising from this project.

time horizons have been used for different approaches. For example, the initial exploratory case study used a cross-sectional time horizon, whereas the data collected from the initial exploratory survey was taken from a longitudinal time horizon. Although mixed-methods were used, data arising from each stage were distinct and were analysed separately. Throughout the project, qualitative data was only analysed using qualitative methods and likewise quantitative data was only analysed using quantitative methods. The analysis was useful for different purposes of the different exploratory and explanatory stages of the study. However, the mixed research methods are useful for providing what Johnson and Onwuegbuzie, 2004 refer to as ’complementarity' of results (i.e. using results from one method to enhance the results from another method used) within the conclusion chapter.

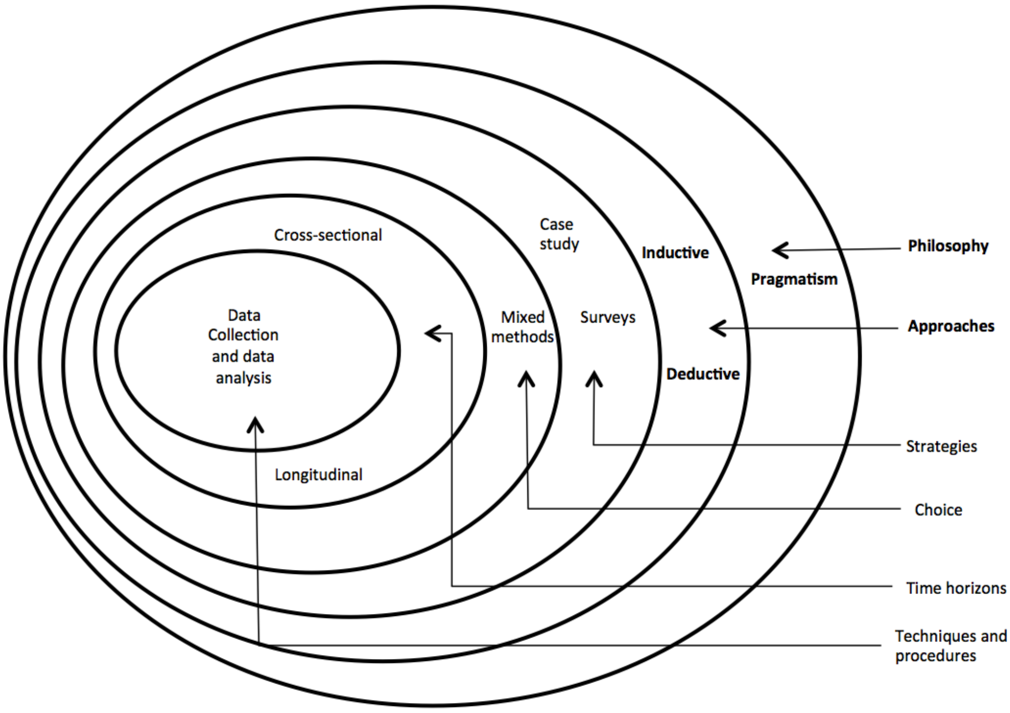

Figure 3.3: Use of Research Onion - to identify philosophy, approaches, strategies, choice and time horizons in study. Adapted from Saunders, Lewis and Thornhill (2009, p108)

3.3.3 Ethical considerations

To contribute to knowledge and ultimately benefit society, good research practice requires conduct that aligns and complies with established, recognised, ethical requirements and standards. Ethics are principles that direct behaviour and activity. Research ethics revolve around practices that provide privacy and confidentiality, avoid deceit and harm, and obtain informed consent. They require researchers to undertake research activity in an "*open and honest manner around data collection, analysis and publication*" (Morton and Wilkinson, 2008).

This multi-stage research project, satisfied the research ethics policy requirements of the awarding institution. Ethical clearance was applied for and received by the Faculty Ethics Committee. It was identified that the project would require data that was likely to be of a commercially sensitive nature which would be gathered via the mixed-method strategy employing the use of case study research, semi-structured interviews, and questionnaires. As the study involved people and personal data, information was supplied to the committee regarding the research population and targeted sample. It was identified that these persons were not considered to be vulnerable groups. All participants who provided consent to be involved in the research were briefed about the research project and its purpose, and provided with details of how the research findings would be disseminated.

Those who participated in the semi structured interviews (including all interviews undertaken during the exploratory case study) completed a University standard 'Research Participant Consent Form' (RPCF), which was provided prior to data collection. This also named the awarding institution, the project supervisors, and the PhD programme of study. The following standard statements around participant consent were provided, reviewed and agreed to by all participants:

- I have been briefed about this research project and its purpose and agree to participate.
- I have discussed any requirement for anonymity or confidentiality with the researcher.
- I agree to being audio taped / videotaped during the interview.

A similar approach was undertaken when using questionnaires to collect data. Summary information was provided about the project, within the introductory, explanatory text provided at the beginning of the questionnaire which included assurances over participant anonymity. After which, the following questions were provided with separate 'YES' and 'NO' response options:

- I understand the purpose of this research and agree to participate?
- I have been briefed about this research project and its purpose and agree to participate?

It is important to note that only questionnaires which attracted 'YES' responses to these two questionnaires were used in the analysis of this work. Evidence of such practice can be reviewed in Appendix D 'Research Instruments. It is also important to note that all necessary procedures around data security, storage, retention, and disposal, that ensured compliance with the principles of the Data Protection Act were adhered to in this study.

3.3.4 Credibility

Finally, to close this section, it is worth noting a discussion on credibility, Saunders, Lewis and Thornhill, (2009) suggest that whatever research decisions have been made, focus is required to make sure efforts or made to reduce the possibility of getting the final answer wrong - and the texts emphasise aspects of 'reliability', 'replication' and 'validity'. Reliability refers to the extent that the data collection techniques or analysis procedures yield consistent findings. Threats to reliability include error and bias, either generated by the research subject or participant, or by the observer - the researcher themselves. Bryman (2012) notes that reliability is concerned with the consistency and stability of the measures devised for the concepts. Replication details the requirements for researchers to outline the procedures used, although Bryman (2102) notes that replication in social research is quite rare. Validity is concerned with *"whether the findings are really about what they appear to be about"* (Saunders, Lewis and Thornhill, 2009). These concerns remained upmost in the mind of the researcher during the course of study and will be addressed within each of the following chapters that detail the various phases of research undertaken.

Chapter Endnotes

[i] There are numerous uses and meanings of the word 'paradigm'. Johnson and Onwuegbuzie (2004, p24) explain that although the concept of a 'paradigm' was popularized by Kuhn (1962) but, "*later, when he was asked to explain more precisely what he meant by the term, he pointed out that it was a general concept and that it included a group of researchers having a common education and an agreement on "exemplars" of high quality research or thinking*". Morgan (2007) acknowledges that the breadth of uses that Kuhn applied to definitions of paradigms led to difficulties, with "*one friendly critic (Masterman, 1970) claimed to have located more than 20 ways that Kuhn used the term his book … Kuhn wished that he had used a different term like 'disciplinary matrix' to summarize the various forms of group commitments and consensus that we now associate with paradigms…. As a result, it is all too easy for social scientists to talk about "paradigms" and mean entirely different things*".

Chapter 4: Preliminary Research - Case Study

To address **Research Objective 3** and examine the development of 4D BIM in the UK construction industry, a mixed-method two-stage exploratory study that encompassed case study, then survey research, was carried out. Before specifically considering 4D BIM, it is worth reviewing what was first learnt about BIM adoption in the UK construction industry. The first stage of preliminary research was of a case study of a single contracting organisation implementing BIM innovation into their work processes which was conducted in the summer and autumn months of 2012. This was followed by the longitudinal online questionnaire survey detailed in Chapter 5, which took place from July 2013 to July 2014 and focused upon the adoption and use of 4D BIM innovation. Both were followed by later 2015 explanatory research into the diffusion of 4D BIM that comprised of concurrent quantitative and qualitative research. The remainder of this chapter focusses upon the exploratory case study research. A classic IDT model helped frame the research questions used[1]. Findings from this case study were published in: *Hybrid project delivery processes observed in constructor BIM innovation adoption* (Gledson, 2016), full details of which, can be found in Appendix A.

4.1 Case study justification and method

The use of case study research has been described by Proverbs and Gameson (2008) as being useful for investigating some phenomena within a context. A case study approach was appropriate for investigating the progress of a BIM innovation implementation-decision made by a large contracting organisation,

1 In this way, the case study research also partially contributes toward Research Objective 1 ‘Examine classic innovation diffusion theory and its applicability to the construction industry’.

planning to adopt the use of BIM across all their future projects. Yin (2009) requires definition of both the case itself, and the unit of analysis to be made explicit within the case study research design. To that end, the case is a regional branch of a large international organisation, and the unit of analysis in this case relates to an aspect of organisational change - the process of BIM innovation adoption by members within that subsection of the organisation.

There is considered to be a "*dearth of research that investigates in qualitative detail processes of implementing innovations within construction*" (Harty, 2008 p1030). This research provided such an opportunity to report on observations of how the organisation and its staff adapted to a programme of organisational change, and can be classified as a revelatory case study. It also reports on how BIM innovation is being diffused into and disrupting the existing working practices of a major contracting organisation. Empirical data were gathered through qualitative interviews and observations made during the implementation stage of the innovation-decision process. An interpretivist approach helped gain insight of employee perspectives regarding organisational BIM adoption. Emphasis was given to the subjects and themes drawn out using open-ended questions on general BIM awareness, and BIM use on the project. In this case study, an iterative research strategy was used (Orton, 1997), where initial literature first informed the construction of the questions and post data collection, thematic analysis afforded subsequent exploration of the literature. The previous literature review chapter explored various aspects of organisational change, construction innovation, and BIM, hence several notable themes from this chapter were appropriate for use in the exploratory research stage. A series of questions were generated that could be asked of construction project practitioners on an early adopter BIM project suitable for case study research. One such project was identified and questions that could be related to various aspects of Rogers (2003) innovation-decision process model, were formulated. This model was introduced earlier in the work and is now repeated in Figure 4.1.

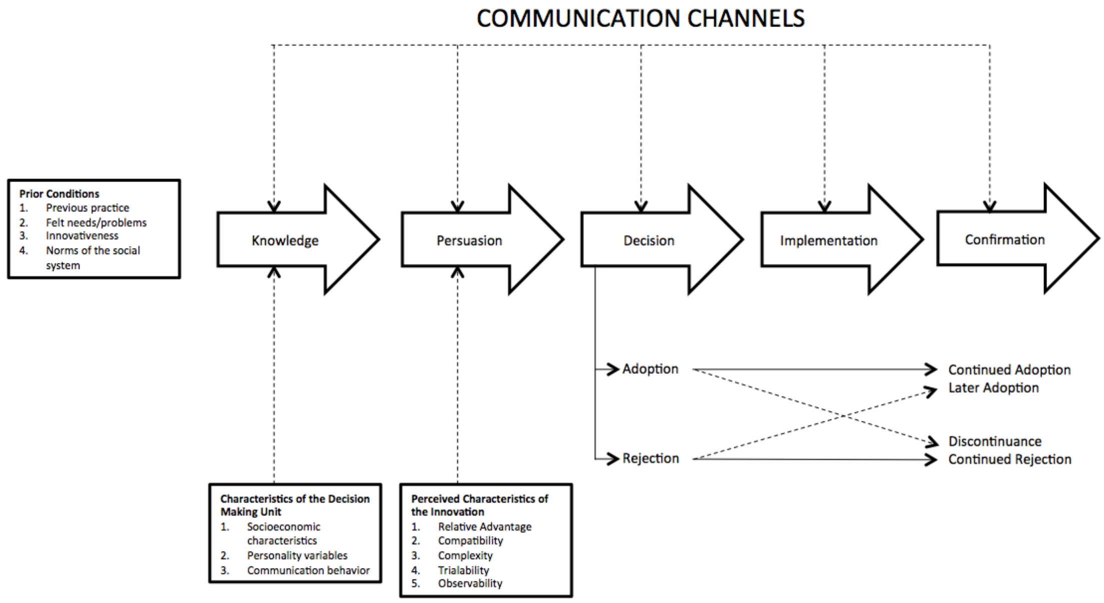

Figure 4.1: Innovation-decision process (Adopted from Rogers, 2003)

These questions focussed on:

- Perceptions related to BIM (relates to Knowledge and Persuasion stages).
- The identification of barriers to BIM implementation found within contracting organisations (Persuasion stage).
- Articulation of the benefits of BIM implementation and current use within contracting organisations (Persuasion stage).
- Key issues or problems that the use of BIM has helped solve in practice (Implementation stage).
- Pre-requisites needed within contracting organisations for the implementation and use of BIM.
- Impact of external factors upon organisational implementation programmes (these last two both relate to prior conditions which impact upon the innovation-decision process).

- Personal observations and experiences of participation in an organisational BIM implementation programme (Confirmation stage).

Appendix D-1 presents the research instrument used. Additionally, **Appendix E-1** identifies the links between the question themes and the relevant literature for all key variables in this research instrument.

4.2 The Case Study

The case study organisation (CSO) operates in international markets and across the UK in construction, property, design, facilities management, and services engineering markets. It is a near permanently fixture within the top 10 contractors as detailed in league tables associated with work winning, profit and turnover. The construction arm of the UK organisation provides new build and refurbishment solutions, operating in: education; office; leisure; health; mixed development; and retail sectors. The organisation has over 2,000 directly employed professionals, and over the 2008–2013 six-year average their UK turnover was approximately £900M. The performance of the organisation closely followed general UK economic performance and the impact of the recession was thus: peak profits were reported in 2008 and peak turnover was reported in 2009 then a decline followed resulting in lowest profits in 2011, and lowest turnover in 2012 before recovery began. CSO made the decision to roll out BIM across all its operations shortly after the release of the 2011 Government Construction Strategy (GCS) and this investigation followed thereafter. The researcher was invited by a regional director to attend the organisations BIM user group meetings, where staff responsible for driving implementation at strategic and operational level across the region coordinated efforts. Issues discussed included company progress, BIM resistance at national and regional levels, and details of BIM partnerships with design consultants and their supply chain organisations.

Increasing engagement with BIM innovation was observed during attendance at these meetings. One observation was of a strategic arrangement between the CSO and a leading software vendor that resulted in a 3 year, multi-million-pound agreement enabling BIM to be embedded throughout their global operations, with vendor technology used on every UK project regardless of size or scale. Archival records on the organisations BIM transition, including internal company documents such as BIM protocols, and external documents including news items were reviewed. Increasing levels of research access was provided over the duration of the case study research allowing evidence to be gathered first through observation and documentation of two of CSO's first BIM projects – a leisure arena, and then a free school, with interviews granted for the latter.

4.2.1 Project A

When research commenced CSO was part way through the process of piloting BIM on a major high profile scheme, a £60m leisure arena project in England (Project A), and the researcher was invited to visit the project. Evidence collected including direct observations, field notes and data from unstructured discussions, although the researcher was unable to formally interview the participants at this stage. On Project A, the organisation had utilised BIM to leverage many efficiencies. They reported cost savings of £350,000 because of clash detection application, achieved a reduction in the production of 9,000 drawing issues saved by using models, reduced onsite working time by 15,000 man hours and material wastage by 8%. Several major design issues had been resolved using BIM and the researcher observed innovative practices by the design team using virtual meetings and web based modelling to achieve remote working, saving over 60,000 travel miles and helping the sustainability performance of the project. These efficiencies persuaded CSO of the value of BIM and reinforced the innovation adoption decision. The researcher was subsequently given further research access to the next BIM project (Project B) whereupon interviews were conducted with six members of CSO staff, a design manager (Participant 2), quantity surveyor (Participant 3), planner (Participant 5), IT manager (Participant 7) and two separate construction managers (Participants 4 and 6).

4.2.2 Project B

Project B was located in a de-industrialised town with a history of socio-economic deprivation. The project was a £8.98 million, part new-build construction of a free school to house 800 pupils. Several existing warehouse and transporting storage buildings had previously occupied the site and industrialised building solutions were implemented with framing elements from two existing structures being incorporated into the new build facility as solutions for sports and dining hall areas. Construction was of a fast track nature that incorporated two distinct phases of work to be handed over to the client. The first phase of work had a planned duration of 35 weeks, which included time for site clearance, demolition and new build with a further phase of 17-week new build period to follow.

CSO had previously completed several Building Schools for the Future (BSF) schemes and although Project A had created organisational experience of BIM, for many of the Project B site team this was their first exposure to the innovation. Procurement was design and build two-stage tender with several contractor design portion packages (CDP) required to complete the solution proposed by novated design team members. The design consisted of a simple steel frame with low-level masonry and cladding to upper levels. Roofing was a mix of standing seam and lightweight sarna materials. To achieve fast track construction and completion within budget, adoption of modular services equipment, reuse of existing building components and foundations and value engineering exercises were undertaken resulting in rationalisation to a fairly simple design. Model coordination efforts for Project B can be seen in Figure 4.2, below. Important challenges included the adoption and use of BIM by the team within a rapid timeframe and use of a hybrid system that maintained traditional project delivery processes whilst also incorporating new BIM processes. Prominent themes that arose within the data analysis were the hybrid nature both of intra-organisation and inter-organisation BIM adoption within the wider Temporary Project Organisation (TPO), the quality of technological interoperability, and reliability of data generated.

Figure 4.2: Project B – Coordinated model management [Photograph]

4.2.3 Process of interview content analysis

NVivo, the Computer Assisted Qualitative Data Analysis Software (CAQDAS) package was utilised as a tool to aid the analysis of the qualitative data arising from these interviews (King, 2009; Yin, 2009). Audio from all interviews was captured digitally and then verbatim transcripts were produced. Interview transcripts were then formatted to meet the requirements of the CADQAS package and imported into the software application. Each section of the interview transcript content was then matched up with the relevant timings of the audio files to facilitate the ease of searching and retrieval of relevant sections of each interview. Codes were pre-assigned to capture and compare responses against each question and to subjects and themes identified in the initial review of literature. Thereafter subsequent coding occurred during the analysis, as other themes also emerged. Part of the interview required the interviewees to consider issues around organisational BIM adoption (benefits, barriers company pre-requisites, impacts of external factors) the remaining part of the interviews focused upon the specific use of BIM on Project B.

Name	Sources	Referen...	Created On	Created By
BIM on this Project	0	0	23 Oct 2012, 17:47	BJG
BIM and FM	1	1	23 Oct 2012, 17:47	BJG
BIM and Work winning	2	3	23 Oct 2012, 17:47	BJG
BIM as a contractual condition	2	2	23 Oct 2012, 17:47	BJG
BIM Execution Plan	2	2	23 Oct 2012, 17:47	BJG
BIM use by design team	3	9	23 Oct 2012, 17:47	BJG
BIM use by supply chain	2	2	23 Oct 2012, 17:47	BJG
BIM use on the project	6	15	23 Oct 2012, 17:47	BJG
Clash detection	5	12	23 Oct 2012, 17:47	BJG
Design production and management process	4	12	23 Oct 2012, 17:47	BJG
Design timescales	1	1	23 Oct 2012, 17:47	BJG
Improvements in predictability or certainty	4	5	23 Oct 2012, 17:47	BJG
Level of investment made	4	6	23 Oct 2012, 17:47	BJG
Model ownership	2	2	23 Oct 2012, 17:47	BJG
Sharing and coordinating data and information	2	3	23 Oct 2012, 17:47	BJG
Software compatibility issues~	4	7	23 Oct 2012, 17:47	BJG
Case Study Project	0	0	23 Oct 2012, 17:31	BJG
Context of project	1	1	24 Oct 2012, 17:32	BJG
Drivers for the project	1	2	23 Oct 2012, 17:31	BJG
Expectations of the client and the end user	1	1	23 Oct 2012, 17:31	BJG
Key challenges of the project	1	7	23 Oct 2012, 17:31	BJG
Offsite solutions	2	3	23 Oct 2012, 17:31	BJG
Project description	2	5	23 Oct 2012, 17:31	BJG
Project specific constraints	1	1	23 Oct 2012, 17:31	BJG
Solutions used on the project to key challenges	4	12	23 Oct 2012, 17:31	BJG
Collaboration	1	1	10 Dec 2012, 18:54	BJG
Field BIM	1	3	10 Dec 2012, 19:05	BJG
General BIM Questions	0	0	23 Oct 2012, 17:43	BJG
Barriers to the implementation of BIM	6	20	23 Oct 2012, 17:43	BJG
Benefits to the implementation of BIM	4	21	23 Oct 2012, 17:43	BJG
BIM Implementation prequsites and necessary elements	3	8	23 Oct 2012, 17:43	BJG
Current outcomes of implementation	5	10	23 Oct 2012, 17:43	BJG
Experiences of implementation	4	12	23 Oct 2012, 17:43	BJG
Impacts of external factors	5	10	23 Oct 2012, 17:43	BJG
Measurable Benefits	1	2	23 Oct 2012, 17:43	BJG
Preconceived ideas relating to BIM	5	12	23 Oct 2012, 17:43	BJG
The future	5	9	23 Oct 2012, 17:43	BJG
Using BIM to solve a key issue of problem	3	3	23 Oct 2012, 17:43	BJG
People	0	0	10 Dec 2012, 12:21	BJG
Planning Questions	0	0	23 Oct 2012, 17:56	BJG
Project Description (Commercial)	0	0	23 Oct 2012, 17:34	BJG
Project Description (Construction Process)	0	0	23 Oct 2012, 17:39	BJG

Table 4.1: Case study 'Nodes'.

4.3 Themes arising

4.3.1 BIM: Preconceived perceptions, fears, concerns and hopes

Because BIM can be categorised as a radical disruptive innovation, first impressions of it were considered to be important. These were mostly positive, although participants variously reported initial limited perceptions over the information rich aspects of BIM and focused more on the improvements in 3D visualisation and in communicating ‘spatial aspects’. It was reported that there had been a strong emphasis on the benefits of clash detection when BIM was first discussed within CSO. Several of the interviewees had experienced immersive aspects of non-intelligent 3D design on a previous project and had considered the application to be useful for purposes of communicating aspects around health and safety and building maintenance. There was recognition that software would merely be an enabler, and that changes in culture and process would be required. Participant 3 noted:

> *"My first initial thoughts of BIM was that it would never work … it just seemed to be too much to expect from everyone … too many members, on too many teams … It’s like a domino effect* [all it takes is] *one person who makes a mistake, then so does someone else … relying on people … it could get out of control … too many people inputting too many things.”*

4.3.2 Barriers to implementation and use of BIM in contracting organisations

These were identified as challenges associated with existing culture and implementing change particularly amongst management members of staff who were perceived to be less ICT capable. Interviewees generalised about the variance in technological capabilities being an issue between different age generations, rather than job roles with both indicating that in their experience younger members of staff had greater ICT abilities than the more senior generation. Participant 6 stated:

> *"We’ve got a broad-spectrum of people here in terms of personality and age and drive within the business, you got the younger more technologically advanced side that are not frightened of technology and embrace it and then you have got an older, less … I was going to motivated but that’s not the right word … less*

> *technologically understanding or capable generation … there needs to be willingness to understand it ... a willingness to get involved with the technology and get away from their own fears and embrace it … if people do that then very quickly you understand that it's really easy to use".*

Conversely it was identified that more junior staff may also not necessarily have the wealth of building knowledge that the senior staff have accumulated, and a two-way transference of ICT and construction industry knowledge between these actors would be necessary. Returning to the theme of *willingness*, interviewees identified that more senior members of staff would expect to receive more structured ICT training where more junior members of staff would be more likely to adopt a more heuristic method of working with BIM. There was concern over the level of investment required, particularly for smaller supply chain contractors, and the perception of attitudes toward commercial risk and legal barriers from organisations who would be contractually engaged with CSO. In terms of technology, there was a large emphasis upon the implications of upgrading existing ICT infrastructure to accommodate resultant larger file sizes and the required increase in upload and downloads speeds, and Participant 7 commented, *"People just expect the infrastructure to be there".*

Commenting on aspects of intercompany processes and current limitations of the technology, Participant 6 stated:

"It's seen to be hard work because the technology is not where it needs to be, I think people have grand visions about what you can do, but the reality is that it doesn't do it just yet, and obviously there is the IFC [technological interoperability] *issue, which doesn't help, and I think once we get through those barriers I can see real benefit in it, but I'm constantly struck by the fact that we can't do what we want it to do".*

4.3.3 Benefits to implementation and use of BIM in contracting organisations

Actual efficiency improvements being realised in practice were described. Participant 3 reported upon time improvements during the process of undertaking the quantification of several structural foundation elements where direct exchanges of readable file types between the BIM applications used by CSO and the structural design consultant had allowed this process to occur. Participants reported that they personally had gained greater understanding of the design, than in comparison to previous projects using only 2D non-intelligent design data. There were reported improvements in communication and understanding by the entire project team, and usage of the model to assist in the management of health and safety. This was done by capturing key visualisations where the delivery team had identified safety concerns in order to communicate these issues to site management staff.

It was confirmed that the use of clash detection technologies had been a key benefit actualised during construction. This was emphasised through several examples including the pre-installation resolution of clashes between main structural steel frame contractor and the roofing contractor, and at different interfaces involving the steel frame contractor and the curtain-walling contractor. The ease that resolution of these clashes were facilitated was discussed by Participant 4: *"I just take a snapshot* [from the model] *and send it to them and say 'we've got a problem here - we need to sort something out' … it's the classic phrase 'a picture says a 1,000 words' - no one can argue when you send them picture that shows a steal beam running through a wall, it is obvious"*.

CSO used a range of different approaches to design coordination through clash detection functionality. The below exchange between the researcher [R] and participant 2 [I] revealed use of the software that enabled automation of 'hard' rule based clashing of parametric objects in addition to a more necessary 'softer' approach of model navigation and interrogation, which was necessary because of poor technological interoperability between BIM files and platforms used on Project B:

> [I] *I'm finding things I wouldn't find ordinarily … with the architect, I've struggled a bit with clash detection, because of the way they build their models. I call it soft clash detection, the ability to make windows opaque and assign a different colour and realise there's a clash, not by [an] algorithm, but just by looking at them and realising that it doesn't look right, so for me it has been the soft clash detection that I've benefited from so far.*
>
> [R] So hard clash detection is when it [the application] automatically does it?
>
> [I] *Yes, there is an algorithm, so you take the steel model, take the cladding model and show where the clashes are.*
>
> [R] So it automates it … soft clash detection is where you manually investigate it How would that have worked before in your role?
>
> [I] *I'm not sure I would have found those things… [I] would have been sifting through lots of drawings, and asking - is that dimension correct? What about that one? But the reality is, we don't have time to do that.*
>
> [R] If you didn't pick it up what would have happened?
>
> [I] *The steelwork would have been in the wrong place, and we would be probably standing [no progress on site] for weeks waiting for steelwork to be moved so the curtain wall could go in.*

4.3.4 Key issues the use of BIM has helped to solve

Participant 6 provided a further example of the benefits of clash detection used to resolve logistical challenges associated with the transportation and positioning of major plant and equipment in a large-scale major industrial unit on Project C, which was in the pre-construction phase of the project delivery cycle:

> *"I have a factory layout of all the equipment that they [client organisation] are going to be bringing in, and they have given us 2D drawing information that we imported that into the model and it clashed with certain steelwork location positions within our model … so the box that they have been given to fit their equipment… included our columns inside of that boxed area. We already knew that there was a problem, so we looked at that and resolved it so we have already use clash detection for process fit out information. So, they provided schematics or two-dimensional information, and then a Company BIM Coordinator remodelled this in a 3D environment to show the routes where the equipment would be delivered down to be installed into their final location".*

4.3.5 Perception of pre-requisites for the implementation and use of BIM

Various responses focussed upon resourcing issues, with participant 3 addressing people issues:

> *"It's just culture, you need people who want to try and learn something different, with the correct attitude,* [and who understand the] *possible benefits … It's just about changing people's attitudes, because there are a few people who don't*

> *really believe in it, but when you have explained what it could do and how you can save money with it has changed their opinion".*

Participant 6 focused on IT investment, *"there is a realisation that* [some] *computers could not actually handle the software",* and identified that CSO had proactively upgraded much of the necessary ICT hardware including workstations and laptops to allow workers to yield the benefits of BIM in advance of the usual cycle of planned ICT expenditure. Tool mapping was emphasised by interviewees in concerns that further expenditure was needed, with more software licenses being required than held, in order to allow staff who have processed the implementation message to be able to access the software and learn how to use the tools to perform the functions required.

Work processes were also considered by participant 4 who first discussed the technological differences and preferences between generations:

> *"Construction as a whole has been a time served thing e.g. 'I've been in this industry for 30 years' - it's trying to get that man to embrace something that he's not used ever, and trying to get him to change - it's getting the man who if you put the model in front of him will still reach for the drawings it's getting him to change that kind of attitude".*

This interviewee provided their perspective of the CSO BIM Innovation implementation strategy: *"They are moving in the right direction and it is developing like BIM itself, so embracing it within the company will be an on-going thing".*

4.3.6 Impact of external factors upon the implementation programme

Only two of the interviewees appeared to have any knowledge of the Government Construction Strategy (GCS) and the 2016 Level 2 mandate. Most responses indicated that these practitioners had little understanding of the 2011 GCS, with their knowledge of BIM coming only from the information provided by

CSO. Participant 4 stated of BIM: *"It allows us to develop designs better and therefore help projects come 'on-stream' earlier, than historically may have happened, so BIM helps the designers value engineer better which then brings down the end price, helping a scheme that might not ordinarily have been approved"*. This participant further discussing the increased use of ICT within construction and continued: *"I think … the economy has empowered people to move forward, because if you can show people you make a saving, everyone is going to jump on board, but I also think the industry as a whole was moving that way anyway, it was the next logical step, ICT has* [now] *come on board… it was only a question of when, but the economy has helped drive that a bit more … I also think the industry was going that way anyway".*

4.3.7 Experiences of the implementation programme

Participants discussed aspects of organisational culture, provided insight into the differing attitudes of company workers toward the innovation, and considered the use of smaller monthly steering groups to facilitate implementation to be a positive approach. Participant 2 recognised that the direction and commitment of company leadership was proving effective in steering organisational change *"I wonder how much of it is organisational as well, I wonder if I was in a different organisation, that wasn't quite as savvy, would I still be pushing ahead to the extent the director has pushed me along – to go off and use BIM on that job?"*

4.4 Discussion

The use of the case study confirms that the innovation-decision process model developed by Rogers (2003) may be applicable across the multiple levels (industry-organisation-project-individual) in that decision-making units go through when considering adoption or rejection of BIM-innovation. In this case study, organisational-level, company leadership and knowledge were perceived as being effective in managing BIM innovation into use. At project-level variations in individual levels of use and adoption were apparent. CSO is an early adopter of BIM innovation, and observation and analysis reveals how such adopters will have to duplicate efforts and employ inefficient *hybrid delivery methods*. Several parallel processes are required to satisfy competing demands and preferences between ICT focused client and consultant transactions; inter-team preferences; and site level paper based needs to undertake project requirements. This is what Rogers (2003) would refer to as an undesirable consequence of innovation adoption. On this project, there were no contractual requirements imposed by the client team that required CSO to adopt any BIM tools, or processes, and at the preconstruction stage, the project largely proceeded in a traditional manner. CSO used these projects as learning opportunities whilst continuing to develop in-house BIM protocols in preparation for future projects. As identified by Gu and London (2010) there was evidence of varying intra-organisational use of BIM. Within the project team this ranged from: using it for entire job role (Design Manager); awareness of benefits but not using it, or not believing that their role should be using it (Construction Project Manager); awareness of benefits and starting to use it to benefit job role (Quantity Surveyor); to scepticism and not using it (Project Planner). This was despite a commitment from CSO that BIM would be used on all its new projects. Individual beliefs and attitudes toward the consequences of BIM working in a TPO align with previous studies (Jacobsson and Linderoth, 2010; Brewer and Gajendran, 2012; Davies and Harty, 2013b) particularly over the immediacies of project deadlines, culture, compatibility with working process and preferences, and technological acceptance. One anticipated organisational challenge would be the deployment of human resources between technologically adverse and technologically accepting persons. These attitudes have been attributed in literature to generational differences between ‘digital immigrants’ and ‘digital natives’ (Prensky, 2001a; 2001b) and were observed first-hand by the researcher and reflected upon by several participants.

On Project B, the design process was managed via rolling two weekly uploads and reviews of consultant team models. Interviewees noted concerns over the hybrid nature of these processes on this project that centred not just inter-organisational BIM use, also on transactions with wider TPO partners. The ‘hybrid production information processes’ for project B can be seen in Figure 4.3 below. Variation in levels of BIM engagement within the information management processes of the consultant team partners was observed. Models were issued by the novated project Architectural team and by the Structural Engineers who both worked with BIM methodology, but not by the MEP consultant or subcontractors with design responsibilities who continued to issue only 2D production information. The inner workings of this project appear to provide further evidence confirming findings from the innovation diffusion literature, i.e. because of difficulties crossing multiple organisational boundaries in a TPO and the separation of projects into distinct stages, construction projects are subject to a slower rate of innovation diffusion (Gambatese and Hallowell, 2011; Harty, 2008; Taylor and Levitt, 2004).

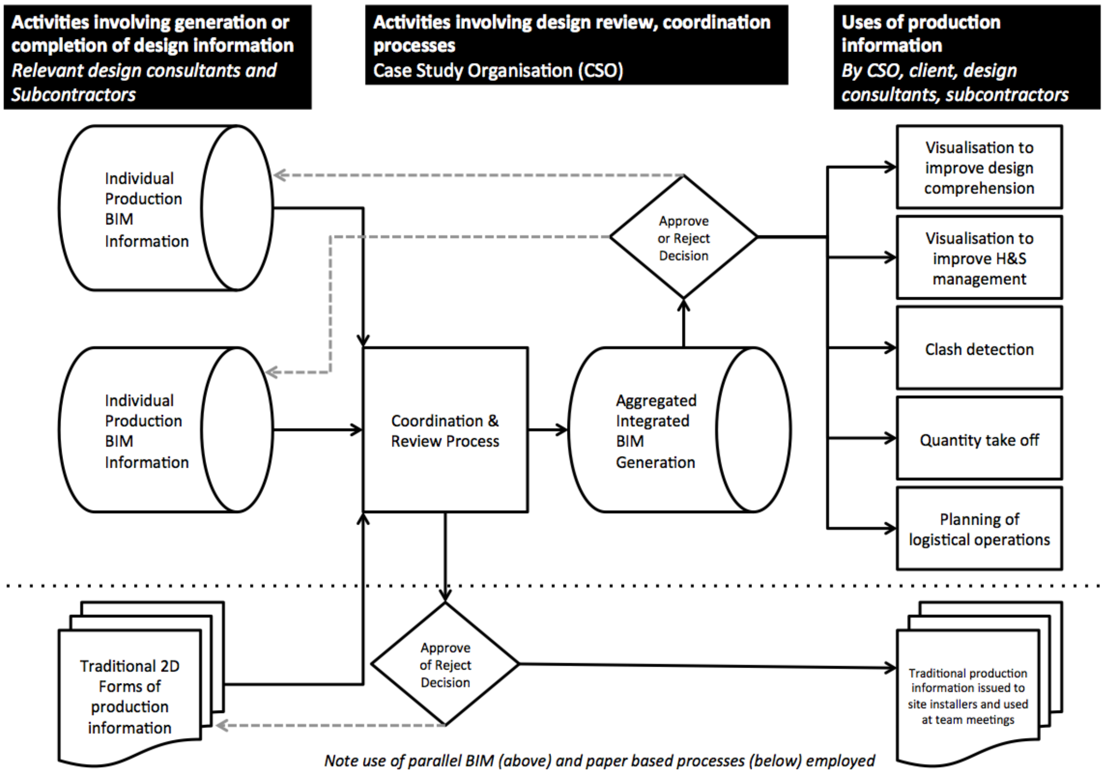

Figure 4.3: Hybrid production information processes employed by CSO on Project B. Researchers own.

One of the biggest challenges facing the diffusion and adoption of BIM innovation is how the innovation should be implemented. More recent research (Arayici *et al*., 2011; Davies and Harty 2013a) argue that implementation should be driven from project-based employees which is analogous to the emergent approach to change within organisational change literature, rather than through top down control (aka the planned approach to change) by corporate management as evidenced in the CSO. These perspectives differ from an earlier model of construction innovation processes, shown in figure 4.4, as developed by Winch (1998) which states that the two dimensions of top down adoption/implementation and bottom-up problem solving/learning approaches are equally as important in the construction innovation process.

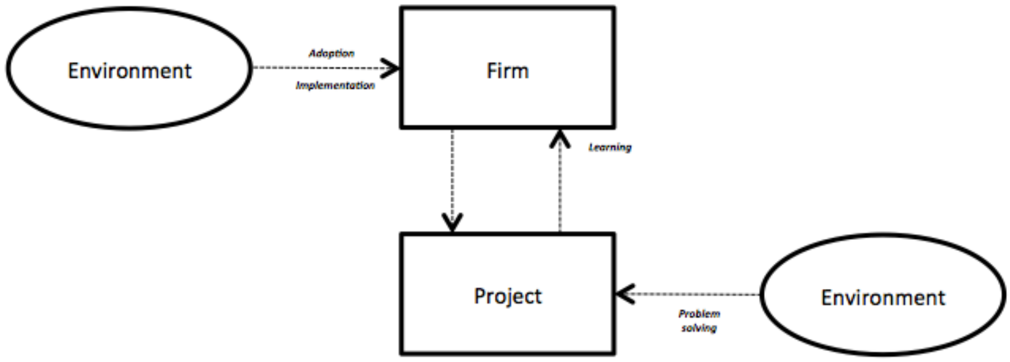

Figure 4.4: Construction innovation processes. Reproduced from Winch (1998)

The researcher observed that coordination between CSO and the consultant team was largely via issue of models, whereas production information was used to engage in client interaction and communication at project meetings was performed solely using 2D drawings. Likewise, all in-house contractor team meetings still revolved around 2D information when discussing issues or problem solving, raising concerns over communication effectiveness. At tender stage, despite the availability of 3D models, all subcontractors were issued 2D information for purposes of tendering and building. CSO reported that site managers were getting familiar with seeing design information in 3D via specially created viewpoints on the model for areas involving increased safety risks or complex build sequences, but also continued to use drawings on site. Post project discussions with the project team revealed that the project was viewed as a missed opportunity from the perspective of engaging key subcontractors including MEP, Cladding and Structural Steel trades to use the model for production aspects such as cutting schedules. Caution was voiced by the Participant 2 when discussing advances afforded by BIM: "*it's improving the process, but it's reducing communication*". Clash detection operations were considered to have been successful on this project – particularly use of 'soft clash detection', although there was an awareness that despite this technique, several clashes had still been missed, also the level of investment remained a concern with a residual belief amongst the staff that training required investment of £10,000 per seat. The TPO experienced noteworthy ICT challenges, particularly issues associated with technological interoperability. A primary concern was the exporting and importing capabilities of what were perceived to be ‘incompatible’ cross vendor ‘Design Authoring Software’ and ‘Model Review and Management Software’ even when making use of industry advocated IFC files.

4.5 Summary of Case Study

Despite obvious limitations of using a single case, this study was useful as the first part of a two-stage exploratory phase of research. Although issues of causality (internal validity) were not the focus of this case study research, the results do have some degree of external validity as they can be generalised beyond the context of this individual project. At particular levels within industry, particularly across comparable organisations who have taken such top-down ‘authority innovation-decisions’ on their projects, BIM innovation diffusion appears to loosely align with Rogers (2003) model of the innovation-decision of [organisational] ‘knowledge’; ‘persuasion’; ‘decision’; ‘implementation’ and ‘confirmation’. This IDT model was used to help frame the research questions used, thus contributing partially toward **Research Objective 1** by examining classic innovation diffusion theory and its applicability to the construction industry, however validation of this model required further investigation. Greater claims of external validity at industry and individual levels cannot be made due to aspects such as ‘structural complexity’ and ‘technology acceptance’, addressed elsewhere in the study.

CSO can be considered to be an ‘early adopter’ of BIM innovation, and organisational leadership and knowledge has clearly been effective in managing the innovation into use for several members of the project team, although variances of individual level of use and adoption were noticeable. As such some of what Rogers (2003) refers to as *undesirable consequences* of innovation adoption were revealed. It was apparent both through analysis of the data and observation how such ‘innovators’ and ‘early adopters’ of BIM-innovation will have to duplicate effort and employ ‘hybrid delivery methods’ in running several parallel processes to satisfy competing demands and preferences, from: ICT focussed client and consultant transactions; inter-team preferences; and site level paper based needs in order to undertake the requirements of the project.

These undesirable consequences have implications for practice. For organisations considering their response to BIM, an interesting parallel can be drawn with a similar programme of innovation-adoption that occurred in the late 1990’s when greater use of IT supported collaborative construction project management (CCPM) web based project management tools were introduced. The legacy of these tools are that initial hybrid delivery processes adopted by construction organisations never led to optimised information management systems and hybrid methods still remain in widespread use. Web-hosted electronic systems are currently used for communication and information transactions with client, consultant and major subcontractor teams, whilst concurrent paper or email-based systems are also used to issue production information to other subcontract organisations. These hybrid systems are inefficient, duplicate effort and reduce available time, and mismanagement can create costly errors in the construction process. These research findings raise concerns that without careful consideration similar hybrid delivery processes for

BIM enabled projects could become normalised across the industry, and these inefficiencies will continue.

This case study also revealed several implications for research into areas that were outside the immediate scope of the doctoral work, such as the need for more focussed research efforts into areas of technological interoperability. Alternatively, research efforts would be welcomed from sociological and process oriented perspectives, to further aid understanding of the consequences of organisational BIM innovation adoption/rejection decisions, particularly in relation to BIM-innovation diffusion within temporary project organisations and across construction organisations. However, for the purposes of this study, it was evident from the case study, that to be able to properly address Research Objectives 3-5 of this study, alternative, larger scale means of data collection and analysis, such as those detailed in chapters 5 and 7, would have to be designed and operationalised.

Chapter 5: Preliminary Research - Questionnaire

This chapter contains the second part of the exploratory stage of the study. A questionnaire survey was designed to address **Research Objective 3** and examine the development of 4D BIM adoption in the UK construction industry. The survey also partially meets several of the sub-objectives of **Research Objective 4** by investigating the diffusion of 4D BIM innovation within UK planning practice, specifically: (4.1) 'explore and explain construction planning functions that 4D BIM is principally being used for'; and (4.2) 'explore and explain the extent of use of 4D BIM Innovation'. The questionnaire survey was designed to address the following research questions generated from the literature reviewed: *"How have contracting organisations adapted their existing practices to utilise BIM innovation and improve project delivery?"* and *"How are contractors using 'alternative' BIM-based methods of planning construction work?"*. Interim results were originally published in the proceedings of the 30th annual ARCOM conference (Gledson and Greenwood, 2014), with final results being published in '*Surveying the extent and use of 4D BIM in the UK'* (Gledson and Greenwood, 2016).

5.1 Questionnaire survey - administration and response

A questionnaire survey was considered to be an appropriate means of data collection for this exploratory stage of the study (Easterby-Smith *et al.,* 2008; Fellows and Liu 2008). A structured questionnaire survey was developed, and using the sampling strategies described in Section 3.2, was distributed to 335 persons matching the population of interest. These were issued for self-completion via mixed-modes of administration over a longitudinal time period between July 2013 and July 2014.

The first means of survey administration was the use of web surveys and the second means were of hard copy questionnaire surveys issued to construction practitioners at BIM innovation professional events. From the total of 335 issued surveys over the time period, 136 full responses were received giving a response rate of 41%. Analysis of responses from these mixed modes show that of the 335 issued surveys, approximately one third of these - 114 were issued in hard copy and 75 responses were received meaning a response rate from this mode of 66%. Two thirds - 221 online invitations were distributed to complete the hosted web survey and 61 full responses were received, meaning a response rate from this mode of administration of 28%. An additional 84 partial responses were received using this mode although these were excluded from analysis due to their incompleteness.

5.2 Design of research instrument: Questionnaire structure

- The first section of the questionnaire contained 13 questions which required the participants to provide information about their industry profile, and consisted of general demographic questions regarding age, job function, job level, experience, and company size in terms of number of employees and annual turnover. This section also included questions requiring participants to indicate their preferred procurement strategies, and provide detail as to the total number and value of any projects they had been associated with that had used BIM in any capacity.
- The second section with 13 questions focused upon issues around BIM implementation and invited participants to select from a ready-made list, the response that best matched their own views on: who they believed to be best placed to manage BIM on a project; the BIM adoption timescale and maturity, both of industry and their own company; the implementation strategy demonstrated by their own company and the impact that they

believed a recent UK economic recession had upon any BIM implementation efforts that their company has pursued. This section also required the participants to rank, perceived external barriers to BIM adoption, internal factors of BIM implementation, and the benefits of BIM innovation.

- The third section containing 8 questions focused upon 4D BIM including 4D planning, virtual construction (VC) and the virtual construction environment (VCE). This section required participants to identify how their companies had used any elements of VC and VCE and compare 4D planning and new methods of working afforded by BIM with conventional planning.

Appendix D-2 presents this research instrument in full. Additionally, **Appendix E-2** identifies the links between the question themes and the relevant literature for all key variables in this research instrument. Data analysis, primarily using univariate descriptive statistics then inferential statistical analyses, was undertaken using the quantitative analyses tool IBM SPSS Version 22.

5.3 Findings - Descriptive Analysis

5.3.1 Section 1 – Participants profile

The profile of the participants was revealed using several general demographic type questions. In terms of job function (Q3), the highest proportion (47.1%; n = 64) of participants was, appropriately, 'Planners', this was not surprising as whilst the sample was random, the title of the questionnaire was *Planning and controlling construction projects using BIM and virtual construction*, and this title will have more appeal to this demographic. The highest frequency of job category (Q5) was identified as middle management level (44.1%; n = 60), with senior management level being the next highest frequency (28.7%; n = 39). In terms of number of years of experience in the construction industry (Q6), persons with 11 to 20 years' experience at the highest with 28.7% (n = 39) of participants selecting that category. The mean participant experience was 13.7 years. In Q8, 55.9% (n = 76) of the participants identified themselves as working for large companies (250+ employees), with 24.3% (n = 33) working for a small company (1-49 employees) and the remaining 19.9% (n = 27) for medium-size enterprises. In Q9 the largest percentage (25%; n = 34) gave their firm's turnover as '*over £500 million per year*'.

Participants were asked to identify their preferred procurement strategy from a list of options provided (Q10). Design and build scored significantly higher than the other categories, with 24.3% (n = 33) of participants identifying a novated D&B route as their preferred option, and 33.8% (n = 46) identifying a preference for an in-house design team D&B route. 21.3% (n = 29) of participants preferred a traditional route, with the remaining participants selecting the procurement strategies of construction management (10.3%; n = 14), other approaches (6.6%; n = 9), management contracting (2.9%; n = 4), with a minority preferring PFI (0.7%; n = 1) procurement route.

In Q12, 54.4% (n = 74) of the participants indicated that they had been involved in 1-5 BIM projects and 8.1% (n = 11) that they had been involved in 6 to 10 projects. Interestingly 2.9% (n = 4) of participants reported an involvement with 50+ BIM projects, and in response to a separate question (Q13), 16.9% (n = 23) indicated that the approximate total value of the BIM projects that they had been involved in was over £100 million(s); though 27.2% (n = 37) reported that they had not worked on any project using BIM '*in any capacity*'.

5.3.2 Section 2 – BIM Innovation

Section 2 revealed details about if and how the participants' organisation was implementing BIM. A majority (63.2%; n = 86), confirmed that their company had started implementing BIM (Q15), and 23.5% (n = 32) started that they were '*planning to*'. Most participants (57.4%; n = 78) thought the government 2016 target to be '*realistic*' (Q16). In Q17, 52.9% (n = 72) assessed their companies' BIM maturity at Level 1, and 30.8% (n = 42) at Level 2+. Most participants (62.5%; n = 85), predicted that by 2016 their company would meet the Level 2 requirements (Q19) with both 16.9% (n = 23) equally believing that they would be in either the Level 1 or Level 3 category.

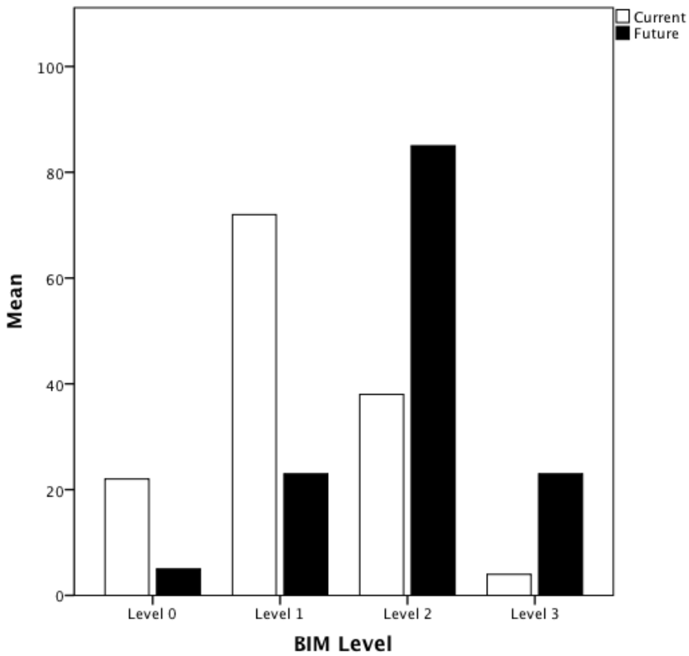

Figure 5.1: Participants assessment of current and future (2016) BIM level categorisation of their organisation

Common to the implementation of any innovation, is the overcoming of cultural barriers to help its acceptance. Q18, addressed this, using Alarcon and Conte's list of 'critical organisational elements' (Alarcon and Conte, 2003, cited in Johansen *et al.*, 2004) which relate to the human aspects of organisational change.

Table 5.1: Participants level of agreement/disagreement that their company has each of these critical elements in their BIM innovation implementation programme.

Critical Element	**Agree**	**As a %**	**Disagree**	**As a %**
Clear methodology	65	47.8	71	52.2
Well defined strategy	56	41.2	80	58.8
Clear direction from upper management	60	44.1	76	55.9
High commitment from upper management	90	66.2	46	33.8
Special task force driving implementation	84	61.8	52	38.2
Key personnel (champions) driving implementation	104	76.5	32	23.5
Adequate knowledge of BIM concepts by most staff at your level	38	27.9	98	72.1
Adequate knowledge of BIM implementation programme by most staff at your level	37	27.2	99	72.8
An effective company communication system	73	53.7	63	46.3
Trial projects	84	61.8	52	38.2
Communicated lessons learned throughout the company	59	43.4	77	56.6

Highest scoring 'agreement' categories include 'key personnel or champions driving implementation' (76.5%; n = 104), 'high commitment from upper management' (66.2%; n = 90), 'special task force driving implementation' and ‘trial projects’ (both 61.8%; n = 84). Highest scoring 'disagreement' categories were 'a lack of adequate knowledge of BIM concepts' (72.1%; n=98) or 'BIM implementation efforts' (72.1%; n = 98) from staff at the same level as the participant. Despite high levels of management commitment indicated, there are many who believe their company does not have a 'well-defined implementation strategy' (58.8%; n = 80); that there is 'no clear direction from upper management' (55.9%; n = 76); the company 'does not have a clear methodology'

(52.2%; n = 71) and does not 'effectively communicate lessons learned throughout the company' (56.6%; n = 77).

In Q20 participants were provided with a list of 8 'external barriers' to BIM innovation implementation identified from the literature, and were asked to place these barriers in order. Using a weighted calculation (items ranked first valued higher than following ranks), the result show '*the fragmented nature of the industry*' itself (725) as the most important issue, with '*time and commercial pressures*' (712), '*culture and human issues*' (699), a '*lack of adequate BIM awareness and understanding*' (696) and '*the structure of procurements and contracts*' (657) grouped closely as the next most important barriers. participants ranked '*lack of leadership*' (525) and issues around education and training (448) as less important with '*lack of proof of performance from measurement systems*' (434) ranked as the lowest external barrier.

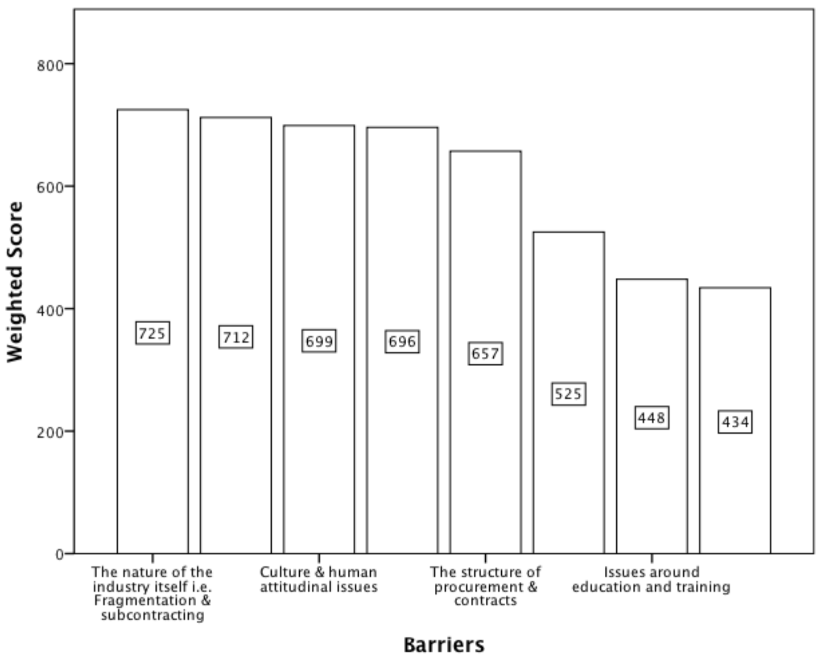

Figure 5.2: Participants ranking of external barriers.

Qualitative comments were also sought regarding further external barriers. Responses demonstrated a preoccupation with client issues, including: lack of ability to articulate requirements; issues of investment and benefits; insufficient time periods being allocated to tender work, and; the suitability of traditional construction project information for purposes of data appropriateness. Notable comments include:

> "*Unclear benefits for Client, the majority of the benefit lie with the contractor*" (Participant 75).
>
> "*Clients not understanding that they need to define what they want from BIM and how they want it using on a project*" (Participant 55).
>
> "*Generally, projects that implement BIM will be driven by Clients who want to be market leaders and not by contractors or design teams*" (Participant 59).
>
> "*There is still a lack of client demand for principal contractors to implement BIM*..." (Participant 83).
>
> "*Lack of client awareness ... and mentality that a traditional BOQ project is cheapest*" (Participant 123).
>
> "*Inadequate lead in periods for the design phase*" (Participant 15).
>
> "*Implementation costs especially to SME's as the capital costs may prove too high*" (Participant 50).
>
> "*Initial investment on technical capabilities* [staff] *and software*" (Participant 77).
>
> "*Return on investment is a key concern for most parties. BIM requires significant direct and indirect costs. The market is leading to tighter margins and therefore an inability to invest in innovation for most SME's*" (Participant 58).
>
> "*Data is often not in suitable format for BIM. e.g. Measurements are required in outdated forms such as SMM7 which use banding rather than an elemental analysis for quantity take-off. Elements are not modelled between 2700 and 3000mm in height, rather at the actual finite dimensions*" (Participant 41).

In Q22 participants were asked to rank, in order of importance, the following three aspects of organisational infrastructure identified by Sacks *et al*., (2010). The intention was to determine the real internal challenges to BIM innovation implementation. Using the same weighted calculation, the participants scored '*people issues*' (302) as being the most significant internal challenge followed by '*process issues*' (281), then '*technology issues*' (233). Using the same method, Q23 asked participants to rank the broad order of BIM innovation benefits.

'*Improvements in communication and collaboration*' scored highest (344) with '*improvements in product (asset) modelling*' scoring (239) then '*process modelling and analysis*' (233).

The next two questions focused on when the participant's organisation began to implement BIM working practices (Q24), and how the participants perceived that the recession had impacted upon these efforts (Q25). In response to Q24, most participants (67.7%; n = 92) identified that their company began to implement BIM working practices after the UK recession that began in mid-2008, whilst 13.2% (n = 18) of participants identified that their company began to implement BIM working practices before this recession began. There were mixed responses to Q25, asking how the recession had impacted upon any BIM innovation implementation efforts, with the largest percentage of participants unaware of how the recession had impacted the implementation programme.

Table 5.2: Impact of the recession upon BIM implementation programme.

Recession Impact	**Count**	**As a %**
My company is not currently attempting to implement BIM working practices	27	19.9
My company was trying to implement BIM before this date and I believe the recession has negatively affected the mentation programme	19	14.0
My company was trying to implement BIM before this date and I believe the recession has helped the implementation programme	12	8.8
My company did not start trying to implement BIM until after the recession commenced and I believe it has negatively affected the implementation programme	23	16.9
My company did not start trying to implement BIM until after the recession commenced and I believe it has helped the implementation programme	13	9.6
My company did not start trying to implement BIM until after the recession commenced and I am not sure how the recession has impacted the programme	42	30.9

Qualitative comments were also sought about the impact of the recession upon BIM implementation within their organisation and responses indicate a lack of available projects, and a focus on leaner delivery methods. Notable data include:

> "*Due to the recession many contractors either rushed through projects to release capital or projects were put on hold. When released, budgets did not move, meaning many were at a loss before breaking ground*" (Participant 34).
>
> "*Decreasing profit margins and greater uncertainty with regards to future workload, leaves business leaders reluctant to make the significant investment required to progress to BIM level 2*" (Participant 15).
>
> "*The recession has forced people to look at leaner ways of working, including BIM. The recession has resulted in a big backward step in the behaviour of clients and procurement teams and their attitudes towards collaborative contracting. Such adversities push companies to reassess the way forward, adapt or die*" (Participant 119).
>
> "*The recession meant that there weren't so many projects, i.e. opportunities to truly implement BIM*" (Participant 127).

5.3.3 Section 3 – 4D BIM Innovation

Section 3 of the survey specifically focused on the use of 4D BIM and the use of Virtual Construction (VC) techniques. The participants were asked to read the following statements familiarising them with these concepts, before answering the questions:

> “*What do we mean by Virtual Construction and the Virtual Construction Environment exactly – is this BIM? Well yes and no, there can be a tendency for people to think of BIM's as just design models, although there is a lot more to them than that such as the use of 4D BIM. For the wider purposes of this investigation we are using the terms Virtual Construction (VC) and the Virtual Construction Environment (VCE) to describe items that will enable the project team to undertake inexpensive rehearsals of major construction processes and test these execution strategies, prior to the actual start of construction, in the 'build it virtually before you build physically' sense. In this analogy, the BIM is the virtual end product and 4D BIM Innovation or ‘VC’ is related to the virtual build process*”.

In Q27, participants were asked to confirm any use of 4D BIM within their company. It was confirmed by 52.9% of participants that their company had used elements of it on live projects, with a further 13.2% reporting that their company had investigated its use but not yet used any elements on live projects. A further

22.1% answered that the company had not used it before and 11.8% were unsure[1].

Q28 asked participants to confirm use of any use of Virtual Construction within the following categories.

Table 5.3: Categories of virtual construction use

Category	Yes	As a %	No	As a %
To win work	67	49.3	69	50.7
To interrogate design	58	42.6	78	57.4
To communicate project timescales	61	44.9	75	55.1
To plan construction methods	66	48.5	70	51.5
To identify scale and working space	49	36.0	87	64.0
To identify hazards	46	33.8	90	66.2
To assist with safety planning	42	30.9	94	69.1
To aid planning for resource management	31	22.8	105	77.2

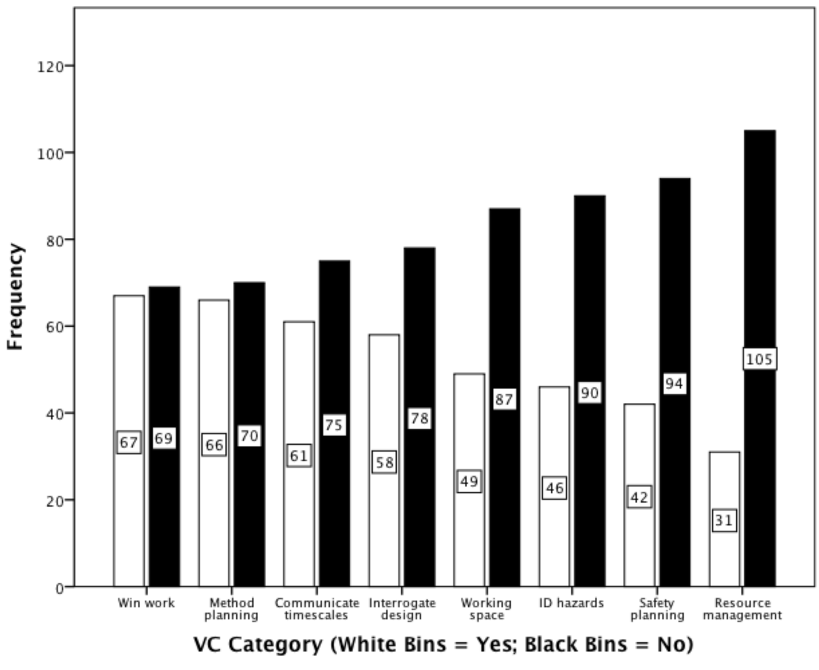

Figure 5.3: Categories of virtual construction use

1 To be able to perform the test of association found in section 5.4.3, these first two responses had to be recoded into a 'Yes in some capacity' option and the second two responses had to be recoded into a 'No' option.

This data shows that whilst all categories score higher in terms of negative responses nearly half of all participants are aware that VC had been used in their organisation to help ‘work winning activities’ (49.3%; n = 67) and to assist in the ‘planning of construction methods’ (48.5%; n = 66). Despite this most responses were negative to many possible aspect of virtual construction use with fewer participants being aware of their organisation using virtual construction for ‘hazard identification’ (66.2%; n = 90), ‘safety planning’ (69.1%; n = 94) and ‘resource management planning’ (77.2%; n = 105).

In Q29, participants were asked to confirm any use of a Virtual Construction Environment (VCE) for site layout planning within their company in the following categories.

Table 5.4: Uses of the Virtual Construction Environment for site layout planning

VCE Element	**Yes**	**As a %**	**No**	**As a %**
Site security	31	22.8	105	77.2
Pedestrian and traffic management planning	54	39.7	82	60.3
Site logistics	63	46.3	73	53.7
Major plant	48	35.3	88	64.7
Temporary works	43	31.6	93	68.4
Welfare facilities	40	29.4	96	70.6
Material delivery and storage	49	36.0	87	64.0

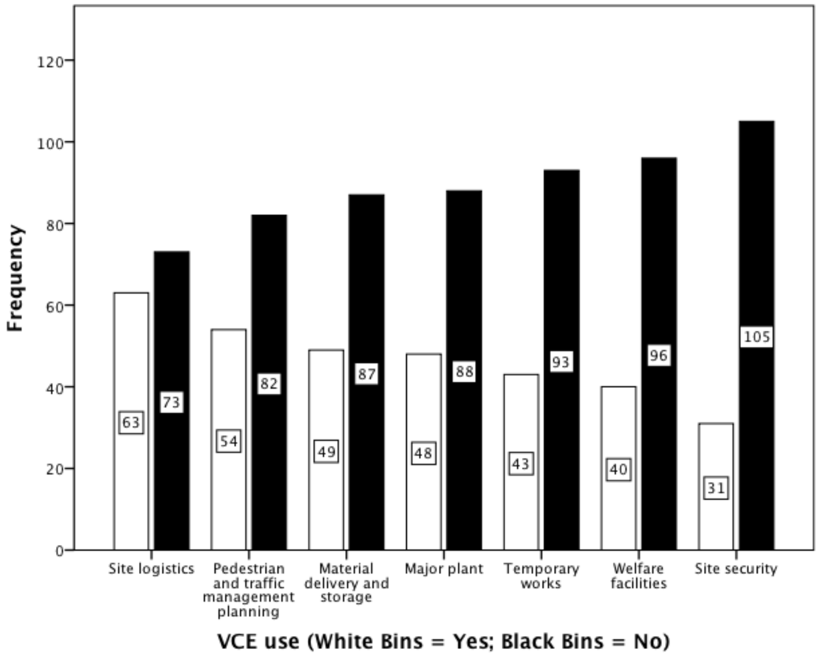

Figure 5.4: Categories of Virtual Construction Environment (VCE) for site layout planning

As previously, all categories scored higher negative counts for '*use of the virtual construction environmen*t', but nearly half of all participants were aware that the VCE had been used in their organisation *to plan site logistics* (46.3%; n = 63).

In Q30 participants were asked the level of value that 4D BIM Innovation would add to their business using a 5 point Likert scale (with responses ranging from 1 being very low value, to 5 being very high value). Most participants (67.7%; n = 92) agreed that 4D BIM Innovation would add high value to their business with level 4 scoring 35.3% (n = 48) and level 5 scoring 32.4%. (N = 44), the mean and median scores were 3.79 and 4.00 respectively.

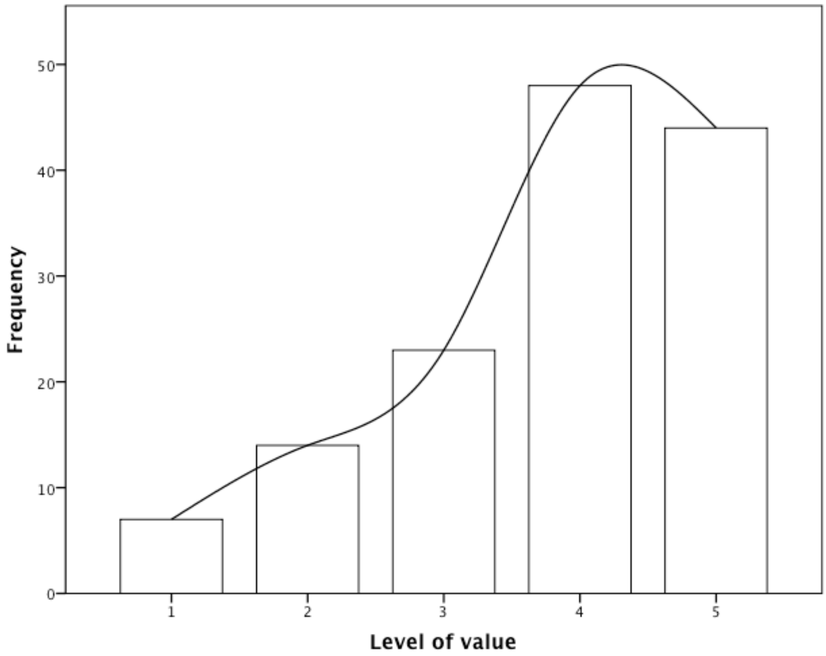

Figure 5.5: Value of 4D BIM Innovation to participants' business

Qualitative comments were also sought regarding the value of 4D BIM Innovation and responses focused on 'project complexities', 'construction sector inefficiencies' and 'work winning/schedule validation' aspects[i].

In Q31, participants were asked to rate how 4D planning may offer improvements over traditional planning processes against a number of aspects. The possible responses were 'traditional planning processes are better than 4D planning'; 'traditional processes and 4D planning processes are equal in this respect'; '4D planning processes offer a small improvement in this respect' and '4D planning processes offer a significant improvement in this respect' (note the percentages have been omitted for clarity in this table). The results are shown in the below table and figures.

Table 5.5: Comparing traditional and 4D planning against aspects of the planning process

Aspect of planning process	Traditional better than 4D	Traditional and 4D equal	4D small improvement	4D significant improvement
Work winning	8	13	36	79
Planning construction process	7	13	46	70
Visualising construction process	4	9	8	115
Understanding construction processes	7	6	31	92
Validating the time schedule	14	24	50	48
Location based planning	11	15	59	51
Progress reporting	15	15	54	52

Despite high negative responses received for questions 28 and 29, the data show that in nearly every category, participants thought that 4D planning offered significant improvements over traditional planning processes.

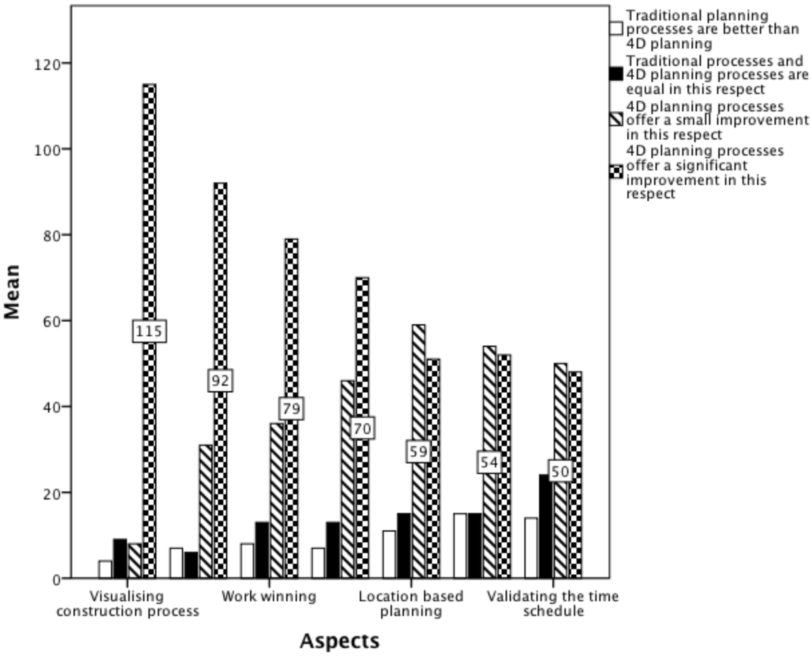

Figure 5.6: Traditional planning process versus 4D planning processes, highest counts shown

The highest-scoring categories were in 'visualising construction processes' (84.6%; n = 115), 'understanding construction processes' (67.6%; n = 92), and in 'work winning' (58.1%; n = 79). The two categories where participants believed that 4D planning processes offered small improvements against traditional planning processes were in 'location based planning' (43.4%; n = 59) and 'progress reporting' (39.7%; n = 57). Traditional planning processes scored low across each category.

In Q32, participants scored each stage of the planning process as identified by Cooke and Williams (2009) in terms of how new methods of working may offer improvements over traditional methods. The same response options were used from the previous question, and the results are shown below.

Table 5.6: Comparing traditional and 4D planning against each stage of the planning process

Stages of the planning process	**Traditional better than 4D**	**Traditional and 4D equal**	**4D small improvement**	**4D significant improvement**
Gathering information	8	24	48	56
Identifying activities	6	27	58	45
Assessing durations	9	38	61	28
Logical relationships	12	21	56	47
Sequence	6	16	52	62
Project timescale	10	28	65	33
Communicating the plan	3	2	23	108

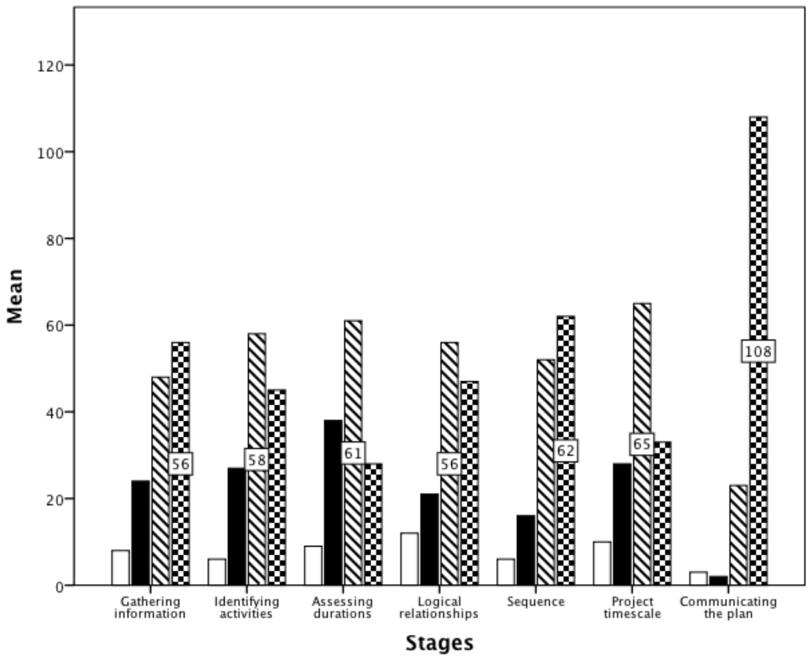

Figure 5.7: Traditional methods versus new methods of working - stages of the planning process (highest counts shown)

The highest-scoring areas of benefit that new methods of working were clearly seen to offer significant improvements was in ‘communicating the plan’ (79.4%; n = 108), in addition, ‘sequence’ (45.6%; n = 62), and ‘gathering information’ (41.2%; n = 56) also scored the highly. In the remaining categories, new methods were seen to offer only a small improvement against traditional planning processes. Two areas where participants felt that new methods did not seem to offer significant improvements were in ‘assessing durations’ and ‘communicating project timescales’.

The final two questions were to determine the ‘extent’ to which the participants' company has used VC in both the method planning (Q33) and time scheduling (34) of construction work. The available response categories were 'used to identify construction methods (in Q33) / construction timescales (in Q34)'; 'used to assess construction methods/construction timescales'; 'used to plan construction methods /construction timescales'; 'used to communicate construction methods/construction timescales'; and 'used to manage construction methods/construction timescales'. Although the most frequent response for each question was that companies had not used VC for these elements (50.7%; n = 69 for ‘method planning’, and 61.0%; n = 83 for ‘time scheduling of construction work’) companies that have used VC have used it primarily to *communicate* their ‘methods’ (36.8%; n = 50) and ‘timescales’ (26.5%; n = 36).

Additional qualitative comments were sought at the end of this section, and the salient responses have been reproduced here:

> "*4D Planning etc. will only be successful if planners/contractors understand BIM technology and have suitable experience of construction practices e.g. BIM won't solve lack of experience or bad planning*" (Participant 90).
>
> “*The view of the team on my project is,4D Planning is only useful where there is an expressed need to understand a sequence of works in more depth. For simple elements this can be a wasteful practice and the question - why are we doing this? - Should always be asked*” (Participant 75).
>
> “*Virtual construction and 4D modelling for us involve much more than mapping a model to a sequence. It involves the integration of project controls, costing, resourcing, design and fabrication, warehousing procurement and other functions. with outputs in many different formats*" (Participant 51).

5.4 Findings - Inferential Analysis

Using inferential statistics, several associations between the extent and use of BIM and 4D BIM innovations, and the characteristics of the user organisations were explored (Tests 1-6). This questionnaire was designed to employ categorical variables, so that the following tests of associations could be performed:

- T1: Company size compared *agains*t company plans to implement BIM innovation.
- T2: Company size compared *agains*t reported organisational BIM Maturity.
- T3: Company size compared *against* company use of 4D BIM Innovation.
- T4: Company size compared *against* perceived value of 4D BIM Innovation.
- T5: Reported organisational BIM maturity *against* company use of 4D BIM Innovation.
- T6: Reported organisational BIM maturity *against* perceived value of 4D BIM Innovation.

In each test, appropriate null (H_0) and alternative (H_A) hypotheses were formulated. To be able to undertake several of these tests, SPSS was used and data were manipulated using the *Transform > Recode into Different Variables* function.

5.4.1 Test 1

H_0: There is no relationship between company size and those companies that plan to implement BIM innovation.

H_A: There is a relationship between company size and those companies that plan to implement BIM innovation.

Company Size (in employees) * Does your company have plans to implement BIM? Crosstabulation

			Does your company have plans to implement BIM?			
			Has already commenced implementing BIM	Is planning to implement BIM	Is not planning to implement BIM	Total
Company Size (in employees)	1-49 employees (classified as small sized company)	Count	15	13	5	33
		% of Total	11.0%	9.6%	3.7%	24.3%
	50-249 employees (classified as a medium sized company)	Count	15	6	6	27
		% of Total	11.0%	4.4%	4.4%	19.9%
	250+ employees (classified as a large company)	Count	56	13	7	76
		% of Total	41.2%	9.6%	5.1%	55.9%
Total		Count	86	32	18	136
		% of Total	63.2%	23.5%	13.2%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	10.766[a]	4	.029	.028		
Likelihood Ratio	10.257	4	.036	.047		
Fisher's Exact Test	10.515			.029		
Linear-by-Linear Association	6.191[b]	1	.013	.015	.009	.003
N of Valid Cases	136					

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 3.57.

b. The standardized statistic is -2.488.

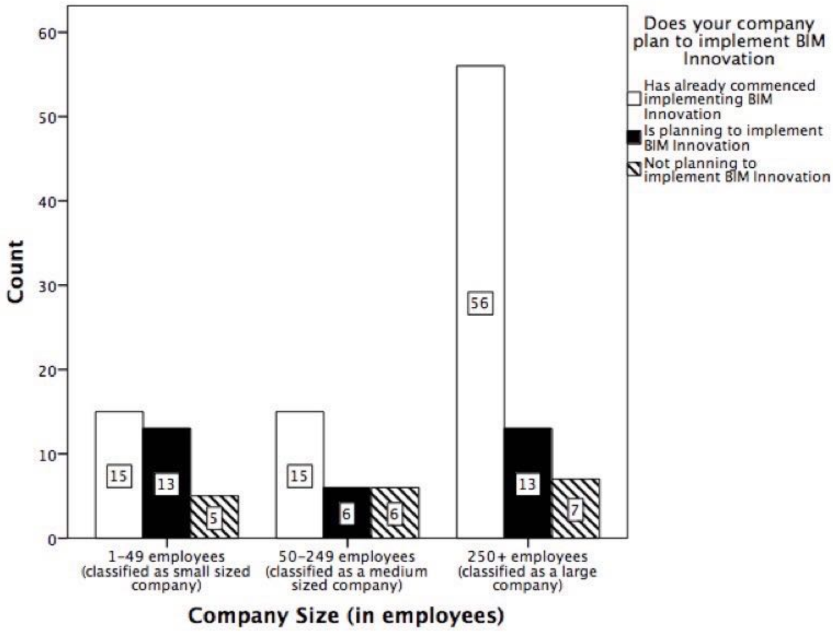

Figure 5.8: Tests of association: Company size against BIM implementation plans

In this test, all 136 cases were usable[2]. A Fisher's Exact Test gave the statistic of .029 meaning that H_0 could be rejected in favour of H_A, that: *There **is** a relationship between company size and those companies that plan to implement BIM innovation.* Interrogation of the data produced in the cross-tabulation about this relationship appears to suggest that larger companies have already commenced BIM innovation.

5.4.2 Test 2

$H_{0:}$ There is no relationship between company size compared with reported organisational BIM Maturity.

$H_{A:}$ There is a relationship between company size compared with reported organisational BIM Maturity.

2 In any tests of association where conditions for X2 were not met because of any expected counts being less than 5, the Fisher's Exact Test was used. This applies throughout the thesis.

Company Size (in employees) * Where (on the diagram) would you assess the current BIM maturity level of your company? Crosstabulation

			Where (on the diagram) would you assess the current BIM maturity level of your company?			Total
			Level 0	Level 1	Level 2+	
Company Size (in employees)	1-49 employees (classified as small sized company)	Count	9	13	11	33
		% of Total	6.6%	9.6%	8.1%	24.3%
	50-249 employees (classified as a medium sized company)	Count	3	20	4	27
		% of Total	2.2%	14.7%	2.9%	19.9%
	250+ employees (classified as a large company)	Count	10	39	27	76
		% of Total	7.4%	28.7%	19.9%	55.9%
Total		Count	22	72	42	136
		% of Total	16.2%	52.9%	30.9%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	9.680[a]	4	.046	.045		
Likelihood Ratio	9.704	4	.046	.053		
Fisher's Exact Test	9.288			.051		
Linear-by-Linear Association	1.745[b]	1	.187	.197	.107	.025
N of Valid Cases	136					

a. 1 cells (11.1%) have expected count less than 5. The minimum expected count is 4.37.

b. The standardized statistic is 1.321.

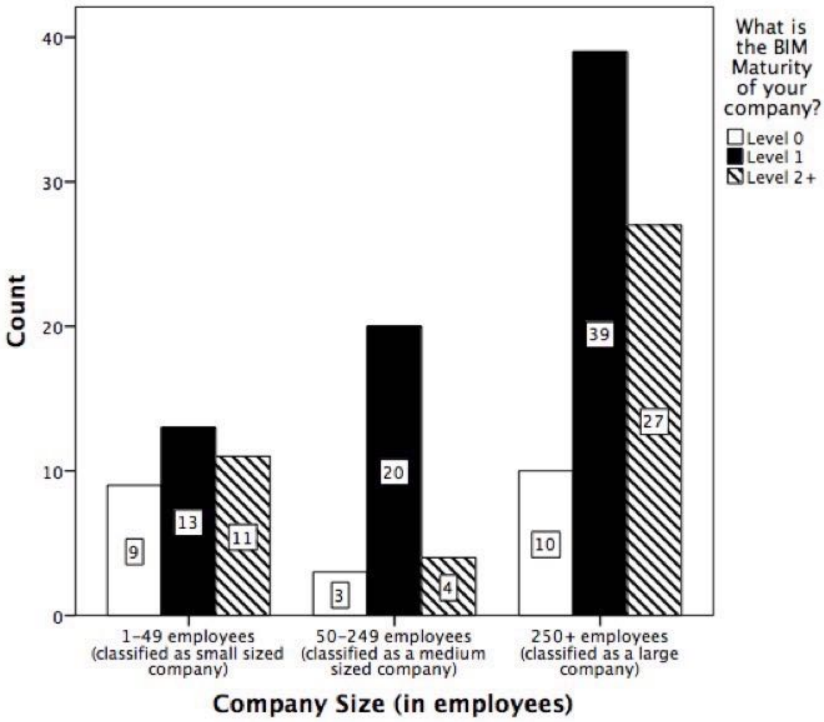

Figure 5.9: Tests of association: Company size against reported organisational BIM maturity

In this test all 136 cases were usable. A Fisher's Exact Test gave a test statistic of 0.51. Despite the close to significant association, this statistic does means that H_0 cannot be rejected in favour of H_A.

5.4.3 Test 3

H_0: There is no relationship between company size and company use of 4D BIM Innovation

H_A: There is a relationship between company size and company use of 4D BIM Innovation

Company Size (in employees) * Has your company used 4D BIM Innovation? Crosstabulation

			Has your company used 4D BIM Innovation?		
			Yes in some capacity	No	Total
Company Size (in employees)	1-49 employees (classified as small sized company)	Count	20	13	33
		% of Total	14.7%	9.6%	24.3%
	50-249 employees (classified as a medium sized company)	Count	20	7	27
		% of Total	14.7%	5.1%	19.9%
	250+ employees (classified as a large company)	Count	54	22	76
		% of Total	39.7%	16.2%	55.9%
Total		Count	94	42	136
		% of Total	69.1%	30.9%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	1.564[a]	2	.457	.485		
Likelihood Ratio	1.528	2	.466	.470		
Fisher's Exact Test	1.544			.501		
Linear-by-Linear Association	.893[b]	1	.345	.378	.202	.056
N of Valid Cases	136					

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 8.34.

b. The standardized statistic is -.945.

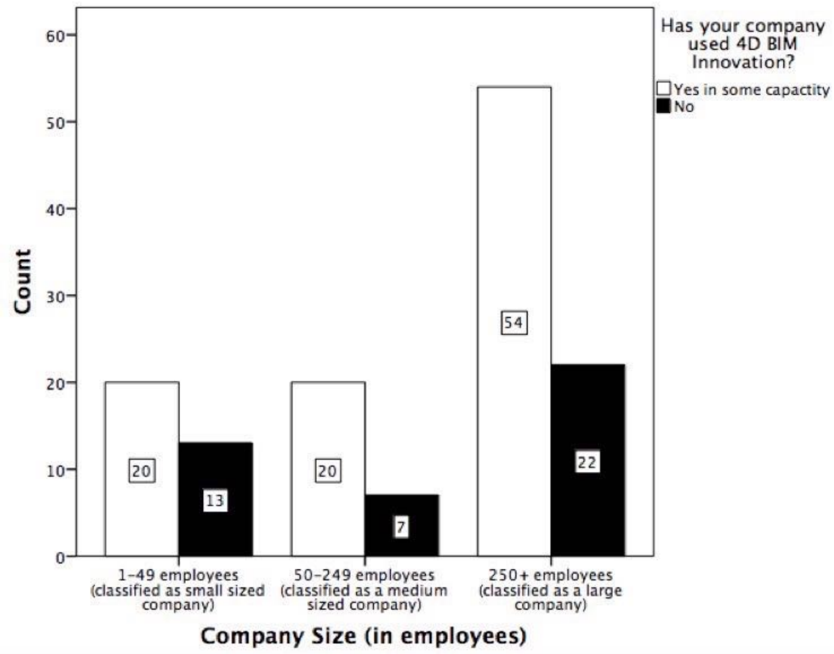

Figure 5.10: Tests of association: Company size against Organisational use of 4D BIM innovation

In this test, all 136 cases were usable. Conditions for X^2 were met and test statistics of .457 and .485 were given. This meant that H_0 could not be rejected.

5.4.4 Test 4

H_0: There is no relationship between company size and the perceived value of 4D BIM innovation.

H_A: There is a relationship between company size and the perceived value of 4D BIM innovation.

Company Size (in employees) * Please indicate the level of value that you believe 4D planning would add to your business Crosstabulation

			Please indicate the level of value that you believe 4D planning would add to your business					Total
			1	2	3	4	5	
Company Size (in employees)	1-49 employees (classified as small sized company)	Count	4	5	3	12	9	33
		% of Total	2.9%	3.7%	2.2%	8.8%	6.6%	24.3%
	50-249 employees (classified as a medium sized company)	Count	1	4	7	5	10	27
		% of Total	0.7%	2.9%	5.1%	3.7%	7.4%	19.9%
	250+ employees (classified as a large company)	Count	2	5	13	31	25	76
		% of Total	1.5%	3.7%	9.6%	22.8%	18.4%	55.9%
Total		Count	7	14	23	48	44	136
		% of Total	5.1%	10.3%	16.9%	35.3%	32.4%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	12.233[a]	8	.141	.139		
Likelihood Ratio	12.063	8	.148	.196		
Fisher's Exact Test	12.069			.124		
Linear-by-Linear Association	3.414[b]	1	.065	.069	.037	.007
N of Valid Cases	136					

a. 6 cells (40.0%) have expected count less than 5. The minimum expected count is 1.39.

b. The standardized statistic is 1.848.

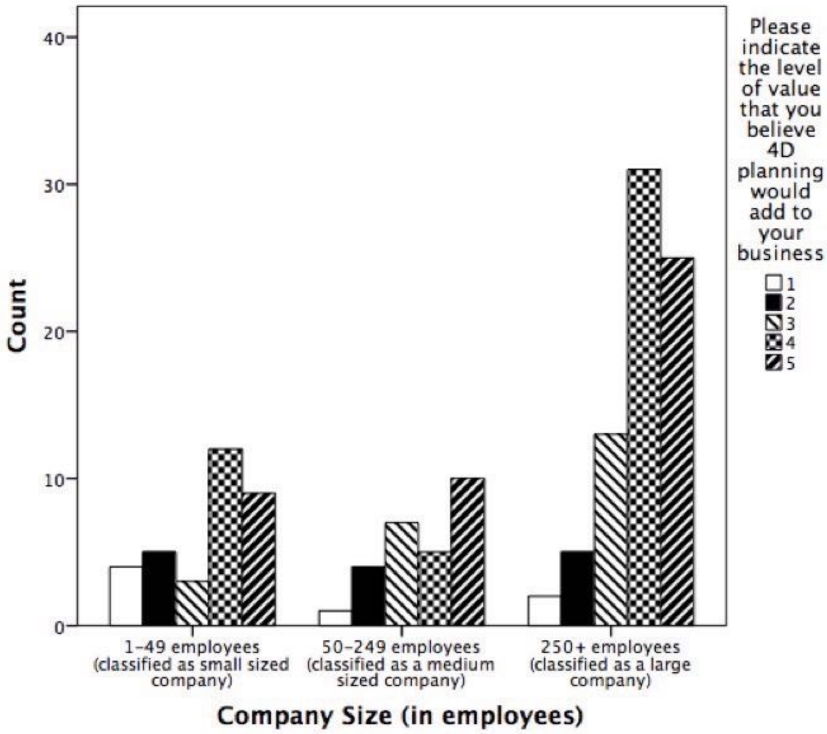

Figure 5.11: Tests of association: Company size against perceived value of 4D BIM innovation

In this test, all 136 cases were usable. A Fisher's Exact Test gave the statistic of .124 meaning that H_0 could not be rejected.

5.4.5 Test 5

H_0: There is no relationship between reported organisational BIM maturity compared against company use of 4D BIM Innovation.

H_A: There is a relationship between reported organisational BIM maturity compared against company use of 4D BIM Innovation.

Where (on the diagram) would you assess the current BIM maturity level of your company? * Has your company used 4D BIM Innovation? Crosstabulation

			Has your company used 4D BIM Innovation? Yes in some capacity	No	Total
Where (on the diagram) would you assess the current BIM maturity level of your company?	Level 0	Count	8	14	22
		% of Total	5.9%	10.3%	16.2%
	Level 1	Count	50	22	72
		% of Total	36.8%	16.2%	52.9%
	Level 2+	Count	36	6	42
		% of Total	26.5%	4.4%	30.9%
Total		Count	94	42	136
		% of Total	69.1%	30.9%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	16.481[a]	2	.000	.000		
Likelihood Ratio	16.216	2	.000	.000		
Fisher's Exact Test	15.793			.000		
Linear-by-Linear Association	15.307[b]	1	.000	.000	.000	.000
N of Valid Cases	136					

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 6.79.

b. The standardized statistic is -3.912.

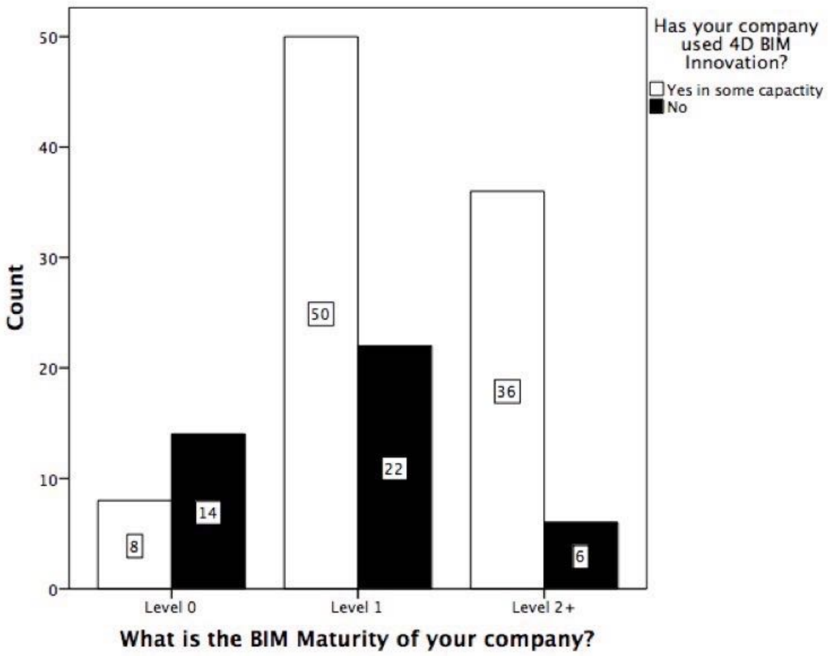

Figure 5.12: Tests of association: Reported organisational BIM Maturity against company use of 4D BIM innovation

In this test, all 136 cases were usable. Conditions for X^2 were met and a test statistic of .000 and was given, which meant that H_0 could be rejected in favour of H_A: *There **is** a relationship between reported organisational BIM maturity compared against use of 4D BIM Innovation.* Interrogation of the data produced in the cross-tabulation about this relationship appears to suggest that as organisational BIM maturity increases so does the company use of 4D BIM innovation.

5.4.6 Test 6

H_0: There is no relationship between reported organisational BIM maturity and the perceived value of 4D BIM Innovation.

H_A: There is a relationship between reported organisational BIM maturity and the perceived value of 4D BIM Innovation

Where (on the diagram) would you assess the current BIM maturity level of your company? * Please indicate the level of value that you believe 4D planning would add to your business Crosstabulation

			Please indicate the level of value that you believe 4D planning would add to your business					Total
			1	2	3	4	5	
Where (on the diagram) would you assess the current BIM maturity level of your company?	Level 0	Count	4	4	1	5	8	22
		% of Total	2.9%	2.9%	0.7%	3.7%	5.9%	16.2%
	Level 1	Count	2	9	14	29	18	72
		% of Total	1.5%	6.6%	10.3%	21.3%	13.2%	52.9%
	Level 2+	Count	1	1	8	14	18	42
		% of Total	0.7%	0.7%	5.9%	10.3%	13.2%	30.9%
Total		Count	7	14	23	48	44	136
		% of Total	5.1%	10.3%	16.9%	35.3%	32.4%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	19.554[a]	8	.012	.011		
Likelihood Ratio	18.756	8	.016	.024		
Fisher's Exact Test	17.380			.017		
Linear-by-Linear Association	6.001[b]	1	.014	.014	.008	.002
N of Valid Cases	136					

a. 6 cells (40.0%) have expected count less than 5. The minimum expected count is 1.13.

b. The standardized statistic is 2.450.

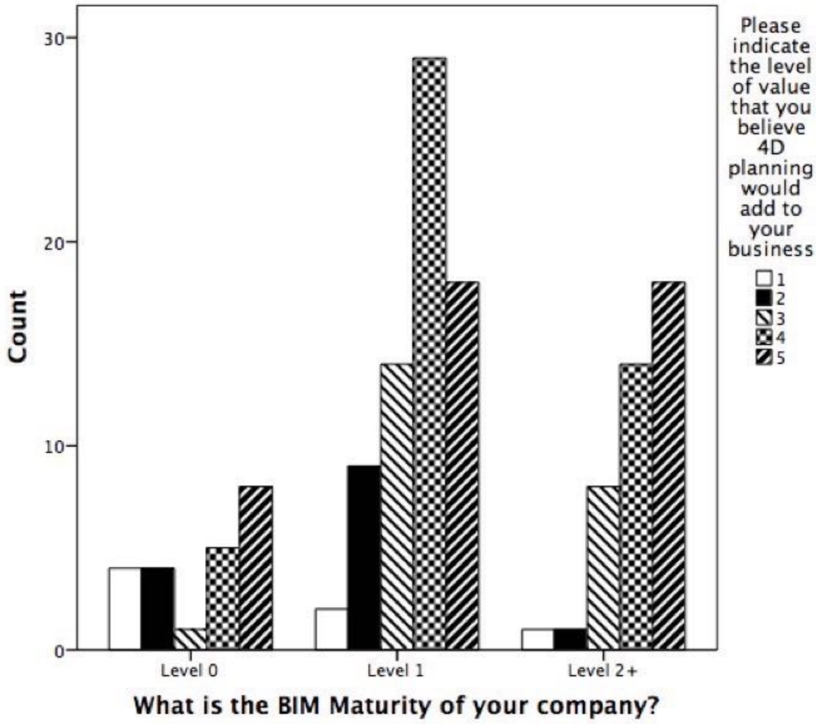

Figure 5.13: Tests of association: Reported organisational BIM Maturity against perceived value of 4D BIM innovation

In this test, all 136 cases were usable. A Fisher's Exact Test gave the statistic of .017 meaning that H_0 could be rejected in favour of H_A: *There is a relationship between reported organisational BIM maturity compared against the perceived value of 4D BIM Innovation.* Interrogation of the data produced in the cross-tabulation about this relationship appears to suggest that as organisational BIM maturity increases so does the perception of the value of 4D BIM innovation.

5.5 Summary of Exploratory Questionnaire

This exploratory stage of the study was designed to address the following research questions: *"How have contracting organisations adapted their existing practices to utilise BIM innovation and improve project delivery?"* and "*How are contractors using 'alternative' BIM-based methods of planning construction work?"*.

Results indicated a high level of BIM awareness and some experience of use of 4D BIM innovation, particularly for work winning, methods planning, and the visualisation and validation of construction processes. The study showed a general recognition of the value of 4D planning, the extent of its use, and those elements of planning which were its principal targets. It also provided a view of drivers and barriers of 4D BIM innovation.

Use of inferential statistics also allowed for the identification of several associations between the extent and use of BIM / 4D BIM innovations, and the characteristics of the user organisations. The results of Test 1 found that there was statistical significance in the relationship between company size and those companies that plan to implement BIM innovation. Larger companies of 250+ employees were much more likely to have already commenced implementing BIM Innovation than small (1-49) or medium (50-249) size organisations and the 74% of the respondent from larger organisations confirming that the company had already commenced planning BIM innovation.

However, these results contrasted with the results of Tests 2 and 3. The results of Test 2 found that there was no statistical significance in the relationship between company size and reported organisational BIM Maturity. Regardless of company size the most frequent response was that organisations considered themselves to be working at BIM Level 1. The results of Test 3 found that there was no statistical significance in the relationship between company size and the company use of 4D BIM Innovation. Regardless of company size the most frequent response from respondents of all organisations is that the company has used 4D BIM innovation in some capacity.

The results of Test 4 found that there was no statistical significance in the relationship between company size and the perceived value of 4D BIM innovation, where regardless of size all companies perceived there to be high value in the use 4D BIM innovation.

In contrast to the results of Test 3, the results of Test 5 showed that there was statistical significance in the relationship between reported organisational BIM maturity compared against company use of 4D BIM and the more mature the organisation in terms of BIM use, the higher the proportion of 4D BIM use in that organisation - e.g. respondents that identified their company as being at Level 2+ recorded proportions of 86% 4D BIM use.

Finally, the results of Test 6 found that there was statistical significance in the relationship between reported organisational BIM maturity compared against the perceived value of 4D BIM Innovation. Regardless of reported organisational BIM maturity all companies perceived there to be high value in 4D planning than not, however differences were much more pronounced in between ‘L0 organisations’ and the ‘L1’ and ‘L2+’ organisations.

The exploratory stage of the research helped to address **Research Objective 3** by examining the development of 4D BIM adoption in the UK construction industry. The questionnaire survey also partially met several of the sub-objectives of **Research Objective 4** by Investigating the diffusion of 4D BIM innovation within UK planning practice. Specifically, these were 4.1: *'*explore and explain construction planning functions that 4D BIM is principally being used for*'*, and 4.2: 'explore and explain the extent of use of 4D BIM Innovation'*,* although Research Objective 4 is more fully addressed in the explanatory stage of the study. Regarding credibility for this second phase of exploratory research design: the research can be replicated, and as the measures used for the concepts are stable it is entirely repeatable. However, because of the impact of the government BIM Mandate; the likely changes to future project requirements and the process improvement BIM journeys that organisations and individuals will go through it is quite likely that different responses would be received should the survey ever be repeated. In terms of internal validity, the survey was not designed to address issues of causality, as these will be addressed in the explanatory stage of the study. In terms of external validity, because of the issues described above of purposive sampling the results of this phase of exploratory research could not be generalised beyond the specific research context. Chapter 6 now follows which details the research design principles for the main explanatory, stage of the project.

Chapter Endnotes

[i]In-between the case study detailed in Chapter 4, and the questionnaire detailed in this chapter, in further exploring this subject, the researcher created an online forum discussion on the professional networking website LinkedIn. This was hosted within a specialist 'group' named '4D Construction Sequencing and Simulation' that had circa 4,926 members. This question was listed: "*Where is the value in 4D planning?*" (link here: https://www.linkedin.com/groups/1777179/1777179-187935530). The thread attracted responses from 11 participants, with the most revealing qualitative data presented here to enhance some of the findings contained in this chapter:

"*There is value, for sufficiently complex projects, with sufficiently ambitious goals … in the UK and worldwide, the only economic sector which has not improved in efficiency and productivity is the construction industry -*

whereas it has been slow at adopting the digital tools that allowed others (manufacturing, services, banking, etc.) to progress" (Participant 8).

"*The purpose of this is to provide more visibility on schedule validation rather than visualise and plan the construction process itself (where the real savings are made) … schedule validation before construction starts can help to reduce exposure to risk, avoid unforeseen costs such as those associated with having to dismantle plant, help with crane planning etc., and helps to improve the quality of decisions made early in the design phase*" (Participant 10).

"*There isn't a big difference between selling/convincing mode and testing/validating mode. Just the audience*" (Participant 12).

Chapter 6: Main Research Design

The findings from the preliminary research stage provide insight into the implementation and use of BIM and 4D BIM innovations. To recap, it was found in the case study that whilst organisational leadership and knowledge is effective in managing BIM innovation into use, there are notable variances between the adoption and usage levels of this innovation between individual employees. It was also found that BIM innovation adoption means that organisations will likely have to employ hybrid delivery methods that require some duplication in efforts in information management processes during project delivery. Findings from the questionnaire show high levels of BIM awareness but only some experience of use of 4D BIM, primarily for work winning, methods planning, and the visualisation and validation of construction processes. The use of inferential analysis allowed for the identification of several associations between the extent and use of BIM / 4D BIM innovations, and the characteristics of the user organisations to be found.

The focus of the work now moves to the design of the main (explanatory) stage of the study (see Figure 6.1), which intends to address **Research Objective 4** by investigating the diffusion of 4D BIM innovation within UK construction planning practice, and **Research Objective 5** using the study of 4D BIM, to develop a model that further informs innovation diffusion theory.

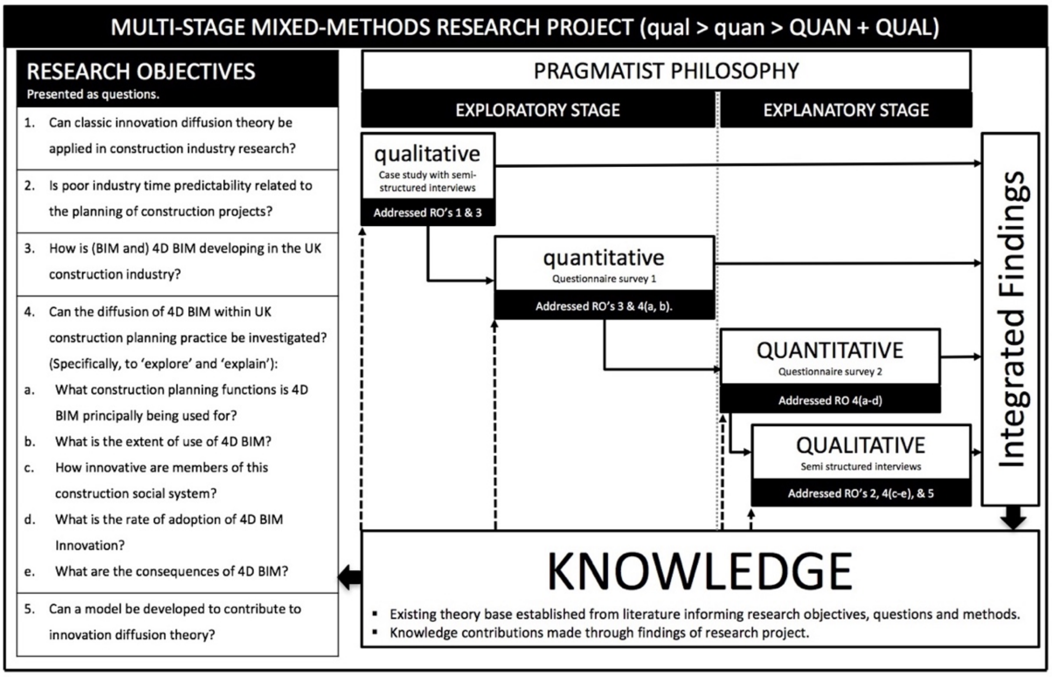

Figure 6.1: 'Road map' of research, showing how methodological approach is linked to research objectives. For reference, identical to Figure 3.2.

To do this, research was designed to take into account key independent variables in innovation diffusion theory, along with several other constructs from the literature review. Rogers (2003) independent diffusion variables were first introduced in the literature review chapter and include:

A. The perceived attributes of an innovation: namely the 'relative advantage'; 'compatibility'; 'complexity'; 'trialability'; and 'observability' of an innovation.
B. The innovation-decision process which is concerned with aspects of innovation 'knowledge'; 'persuasion'; 'decision'; 'implementation' and 'confirmation'.
C. The effectiveness of communication channels.
D. Key actors from within the social system such as 'opinion leaders', and 'change agents'.
E. Classification of adopt-reject decisions.
F. The consequences of innovation adoption.

Several of these variables (A, C, E, and some of the innovation diffusion process aspects contained within item B) were incorporated into the design of a subsequent questionnaire reported in Chapter 7 (See Figure 6.2): whilst all of them (A-F) were also were used in the design of the questions for the semi-structured interviews detailed in Chapter 8.

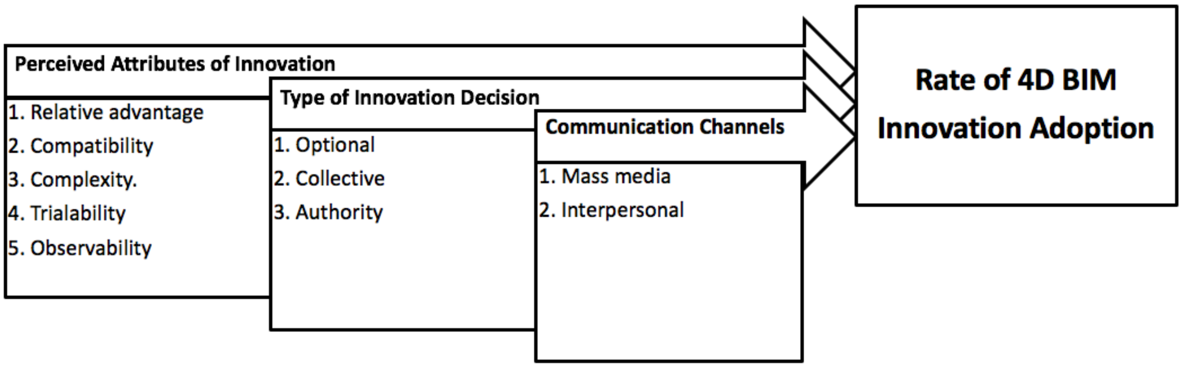

Figure 6.2: Variables determining the rate of 4D BIM innovation adoption. Adapted from Rogers (2003)

The remainder of this section now focuses on providing a fuller description of each of the key independent innovation diffusion variables used within the research design for both the quantitative questionnaire and the qualitative semi-structured interviews. These primarily draw upon the work of Everett Rogers, although other relevant construction diffusion research is noted where applicable. The following chapter (7) then provides further detail of the design and findings from the questionnaire. Thereafter subsequent chapters (8–9) report on the findings from the semi-structured interviews. These chapters will also advise when necessary, where literature informed the development of the questions.

6.1 How IDT variables were adapted and used for this research

6.1.1 The perceived attributes of an innovation

Rogers (2003) describes how individuals differing perceptions of an innovations' characteristics can directly affect the adoption rates of the innovation. The perceived attributes of an innovation therefore help explain these rates of adoption.

i. 'Relative advantage' is defined as "*the degree to which an innovation is perceived as better than the idea that it supersedes*" (Rogers, 2003). It is important to stress that it is this perception of any advantage, held by the individual in relation to the existing idea, which is of the most importance, rather than the actual degree of advantage that could be objectively measured. Diffusion theory considers that the more favourable the perceptions of any advantage that an innovation has, the greater increase in adoption rate is anticipated. In the questionnaire, various functions of traditional construction planning practice and traditional construction planning process were identified from within literature, and the participants were required to assess the 'relative advantages' attributes of 4D BIM against these functions.
ii. 'Compatibility' is concerned with consistency of a potential adopters' experiences, needs and values. Diffusion theory states that innovations that are incompatible with existing infrastructures will not diffuse as rapidly as innovations that are compatible. In the questionnaire, participants were asked to consider whether the use of 4D BIM is compatible with the current practice of construction planning.
iii. 'Complexity' is concerned with perceptions of the relative difficulty of use. Diffusion theory states that ease of comprehension by potential adopter's aids adoption rate. In the questionnaire, participants were

asked to consider whether the 4D BIM planning practices would be difficult to learn, and also, if they would be difficult to understand.

iv. 'Trialability' is concerned with the opportunity to experiment and use the innovation on a limited basis. Diffusion theory states that innovations that can be trialled without commitment are more readily adopted. In the questionnaire, research participants we asked to consider if 4D BIM methods would have to be experimented with before using to plan real construction work.

v. 'Observability' is concerned with visibility of the results of an innovation. Diffusion theory states that innovations that are more visible or have more visible positive results are adopted more readily. In the questionnaire, research participants we asked to if it was easy to see the impact that 4D BIM has on construction planning effectiveness.

Rogers (2003) offers an important summary point regarding the perceived attributes of an innovation *"Innovations that are perceived by individuals as having greater relative advantage, compatibility, trialability, and observability and less complexity will be adopted more rapidly than other innovations".*

6.1.2 Innovation-decision process.

The innovation-decision process is the process through which an individual (or other decision-making unit) passes from first knowledge of an innovation to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision (Rogers, 2003) The innovation-decision process is illustrated in Figure 6.3.

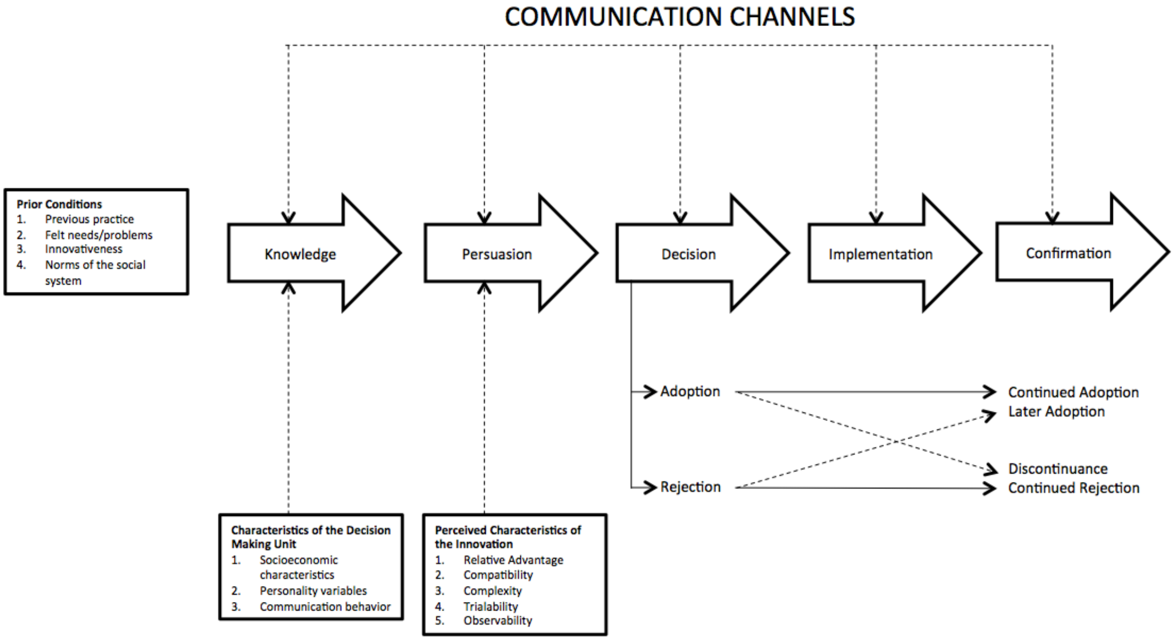

Figure 6.3: The innovation-decision process. For reference, identical to Figure 2.2

The process occurs over a period of time which Rogers categorises into 5 stages. The first stage is of initial 'knowledge' which is generated upon first experience of an innovation, the above model illustrates that the characteristics of a decision-making unit (which could be an individual or an organisation) act as determinants and affect both the earliness of awareness, and attitudes toward an innovation. Such characteristics could include the likes of wealth, levels of education and social status. The second stage, 'persuasion' occurs when an impression or attitude is created about the innovation. This attitude could be that of a positive, negative or apathetic position. The model illustrates that the perceived characteristics of 'relative advantage', 'compatibility', 'complexity', 'trialability' and 'observability' of an innovation play a role at the persuasion stage. The third stage 'decision' occurs when a decision-making unit elects to adopt or reject the innovation. The above model illustrates that each choice has different implications, and that decisions can change. They indicate that an initial decision to adopt can be followed by continuous adoption, or later discontinuance, of use of the innovation. Conversely an initial decision to reject an innovation can be followed by continuous rejection or alternatively by later adoption. In addition to a ‘firm’ adopt or reject decision, rejection can also occur passively where use of the innovation is never contemplated. If however, the decision is to adopt, then this will be followed by a fourth stage ‘implementation’ which is when the innovation is used. Use of the innovation may be identical to how other adopters have used the innovation or some degree of ‘re-invention’ may occur by which the innovation or its use may be modified or altered to suit the needs of the adopter. A final stage, ‘confirmation’, occurs when a decision-making unit tries to obtain ‘reinforcement’ regarding the decision made, although it is possible that seeking such reinforcement may lead to subsequent rejection because of new information. The model also recognises that at each stage, communication channels continue to impact upon this process. The nature of communication channels are discussed below.

In the semi-structured interviews, participants were asked a series of questions on 4D BIM focusing on each of the different stages of the innovation-decision process. Additionally, the questionnaire survey also gathered information about the early stages of the innovation-decision process as participants were asked to record the date of first awareness and first use (recorded in years), directly relating to the knowledge and decision stages. The series of questions mentioned above relating to the perceived attributes of an innovation also relate to the persuasion stage.

6.1.3 Communication channels.

Diffusion theory considers that communication channels can impact upon the rate of adoption of an innovation. Rogers (2003) makes the distinction between the originating ‘source’ of a communication and the ‘channel’ through which it is sent and categorises communication channels as ‘external’ mass media communication channels and ‘internal’ interpersonal communication channels. Rogers (2003) makes the point that external mass media communication channels (such as print media, broadcast media, new online media) can quickly reach bigger audiences than could be done through internal interpersonal channels, although these also help with understanding and comprehension as well as information dissemination. External channels are more important at the knowledge stage of the innovation-diffusion process, whereas internal channels are more important at the persuasion stage as they involve two-way, dynamic, face-to-face exchanges of information which help decrease resistance to adoption, and secure greater favourable attitudes toward an innovation. Rogers (2003) diffusion theory states that the adopter categories of innovators and early adopters are more susceptible to external communication channels where internal communication channels are more favourable to late adopters and laggards. Interpersonal communication is particularly useful for innovation diffusion if the information transfer is truly internal – meaning it is between near-peers, with someone from within the interpersonal network of a potential adopter rather than with external experts.

In both the questionnaire and semi-structured interviews, participants were asked to select their preferences between external sources (*advised as sources such as mass media including websites, journals, magazines and government*) and internal sources (*advised as colleagues, peers, workmates or interpersonal networks*) for both obtaining information about 4D BIM and which of these sources would have the biggest impact on their own personal adoption or rejection decision. In the semi-structured interview participants were also asked to expand upon their selections.

6.1.4 Key actors from within the social system.

Whilst individual adopters can be categorised depending upon their timing of their innovation adoption (either as 'innovators', 'early adopters'; 'early majority'; 'late majority' or as 'laggards'), key actors involved in any innovation diffusion efforts can also be classified as 'opinion leaders' and 'change agents'. Whilst 'cosmopolite' and external facing innovators make up the first 2.5% from within a system to adopt an innovation (Emmitt, 1997; Rogers, 2003; Taylor and Levitt, 2004; Goldenberg and Oreg, 2007), 'localite' and internal facing opinion leaders, who are more rooted and respected within their own social system (Rogers, 2003; Mäki and Kerosuo, 2015) are more likely to be categorised as an early adopter in relation to their timing of innovation adoption (*they are more likely to be from within the next 13.5%, i.e. the first 15% total*). An opinion leader is someone who can provide information and advice about innovations within their social network, often in an informal role, as such they are, "*used to gain awareness and to help influence opinion regarding an innovation*" (Larsen, 2011). Opinion leaders are often considered as actors who positively promote an innovation, but because of their influence, they can impede as well as promote diffusion (Emmitt, 1997; Rogers 2003). Emmitt (1997) believed the roles of 'gatekeepers' and 'opinion leaders' to be synonymous even though his description of gatekeepers is somewhat negative - someone who can actively, "*withhold(s) or alters information as it passes him or her, into the social system over which they have a certain amount of control*" (Emmitt, 1997, p96). Nonetheless, opinion leadership is not typically thought of as involving people with negative intentions regarding diffusion, rather they have respect and informal influence. Rogers (2003) conversely argued that it is the innovator what performs the gatekeeping role allowing, "*the flow of new ideas into a system*".

A change agent is someone external from the social system of decision-making unit who acts as a link between generators and potential adopters of innovations. This is done to influence the innovation-decision process in a particular manner. As identified by Rogers (2003), "*Change agents operate interventions, defined as actions with a coherent objective top bring about behaviour change in order to produce identifiable outcomes*". They are typically employed by a change agency to influence potential adopters in a desired direction. Change agents often make use of demonstrations to allow potential adopters to observe the innovation in use and to help form a favourable opinion. Research undertaken by Hartmann and Fischer (2009) on end user resistance during construction IT implementations found that resistance by potential adopters of an innovation could lead to dialogue about the innovation between change agents and potential adopters, and such dialogue could be found to be an important precursor to successful implementation.

In this research, participants were provided with descriptions of opinion leaders and change agents and during the semi-structured interviews participants were asked to consider in relation to 4D BIM: *"Can you recall any particular interaction with individuals who fit these descriptions, and how this interaction impacted upon the innovation-decision process?".* In addition, the questionnaire required participants to advise of their socioeconomic attributes including wealth, highest level of education achieved and social status. Such data provides useful indicators for assessing the timing of adoption decisions to be able to determine where the participant fits in the adopter categories, as well as helping identify any innovators and opinion leaders within the responses received. In addition, as previously discussed, they are also useful factors when considering matters around the knowledge stage of any innovation-decision process that the individual may undertake.

6.1.5 Classification of adopt-reject decisions

The above descriptions have referred to a 'decision-making unit'. This can be interpreted as an individual or a collection of people. It is more usual in the construction industry that more than one person is involved in making decisions over whether to adopt or reject an innovation. Within larger companies it may be that an organisation has to make a strategic decision to adopt an innovation, before an individual working for that organisation can then subsequently adopt it, whereas with smaller enterprises there may be more flexibility at individual level. There is a need then to understand the types of innovation decision that can be made. Remaining consistent with Rogers (2003) diffusion theory, these types are:

i. 'Optional innovation-decisions': Made by individuals regardless of decisions made by other persons within the social system.
ii. 'Collective innovation-decisions': Made by consensus with other persons within the social system (e.g. committee decisions)
iii. 'Authority innovation-decisions': Made by a single person or small handful of people who possess the power to be able to command the other persons within the social system to comply with their decision (e.g. company directors).

In addition, sequential combinations of any of the above decision types can also be made which can be considered as a 'contingent decision'. In this research the questionnaire provided a description of the three main types of decision classification and required the participant to categorise any innovation adoption or rejection decision into one of these categories. If no decision had yet been made, participants were also asked to explain which type of decision would be made to adopt or reject 4D BIM.

6.1.6 The consequences of innovation adoption.

There are always consequences involved in any innovation adoption, and despite any ‘pro-innovation bias’, these consequences can be negative as well as positive. However, there is little research in the way of the consequences of innovations and Rogers (2003) attempts to clarify why this might be. He suggests that change agencies assume or over emphasise that all aspects of innovation will be positive; data collection methods are usually inadequate; and the effects of consequences are not readily measured. Rogers (2003) believed that it would be useful to analyse three dimensions of consequences:

i. ‘Desirable’ versus ‘undesirable’ consequences
ii. ‘Direct’ versus ‘indirect’ consequences
iii. ‘Anticipated’ versus ‘unanticipated’ consequences.

Participants were also asked to consider these three dimensions of consequence in relation to 4D BIM in the semi-structured interviews.

6.2 Chapter Summary

This chapter has detailed aspects of the design of the main explanatory stage of the study and provided information on several of the key variables from classic diffusion theory. It has been identified how these variables were used with the questionnaire survey and semi-structured interviews to satisfy **Research Objective 4** by investigating the diffusion of 4D BIM innovation within UK construction planning practice. Three of the remaining sub-objectives were addressed by helping explore and explain: (4.3) ‘the innovativeness of members of the construction social system’; (4.4) ‘the rate of adoption of 4D BIM innovation’, and (4.5) ‘the consequences of 4D BIM innovation’. The next chapter of the work focuses on the results of the data collected through the second questionnaire.

Chapter 7: Explanatory Questionnaire Survey

The next three chapters detail the explanatory stages of the study. This chapter focuses on the results and analysis of data collected via a second questionnaire. As previously discussed, constructs from IDT and wider literature informed the questionnaire design. This chapter aims to more fully address **Research Objective 4** by investigating the diffusion of 4D BIM innovation within UK construction planning practice. Specifically, four of its five sub-objectives are covered, by exploring, and explaining the: (4.1) ‘construction planning functions that 4D BIM is principally being used for’; (4.2)[1] ‘extent of use of 4D BIM innovation’; (4.3) ‘innovativeness of members of the construction social system’; and the (4.4) ‘rate of adoption of 4D BIM innovation’. Some of these sub-objectives (4.3–4.4), along with the fifth (4.5), ‘the consequences of 4D BIM innovation’. Will also be considered across Chapters 8 and 9, which provides analysis of the semi-structured interviews held.

7.1 Design of research instrument

7.1.1 Survey administration, population, sample, and response rate

The same principles discussed in section 5.1 ‘Questionnaire survey - administration and response’ were applied in the design of this second structured questionnaire: a mixed-mode of survey administration that encompassed the issue of hard copy questionnaire surveys and online surveys was undertaken; with questionnaires being distributed to purposively selected construction professionals for self-completion. The survey had a cross-sectional time-horizon between April and July 2015. The title of the questionnaire was *Investigating the diffusion of 4D BIM innovation*. A total of 97 full responses were received and an

1 Sub-objectives 4.1 and 4.2 were also partially addressed within the results of the exploratory questionnaire survey, which is detailed in Chapter 5.

additional 54 partial responses were received although these partials were excluded from analysis due to their incompleteness. Initial interim results were published in the proceedings of the 31st annual ARCOM conference (Gledson, 2015), details of which can be found in Appendix A.

7.1.2 Questionnaire Structure

The first section of the questionnaire contained 11 questions which required the participants to provide information about their industry profile, and consisted of general demographic questions, many of which were also included in the exploratory questionnaire. These questions included ‘sex’, ‘age’, ‘job function’, ‘job level’, ‘experience’, ‘company size (in terms of number of employees)’, and the ‘maturity of their organisation (in terms of age)’. In a further repeat from the exploratory questionnaire, the participants were asked to identify their perception of the current BIM maturity level of their company. Two additional questions regarding the ‘highest level of education achieved’, and the ‘total household income’ of the participant were also added, as these had been identified as independent variables highlighted in diffusion research. IDT literature argues that these variables impact upon the ‘cosmopoliteness’, ‘resources’, and ‘social status’ of members in a social system, which is related to adopter categories.

The second section with 7 questions focused upon 4D BIM innovation, and was designed to obtain: ‘timing of first awareness’; ‘confirmation of use / awareness of use of 4D BIM’, ‘timing of first adoption’, and ‘confirmation of the perceived value of this innovation’.

A third section contained 25 statements on the perceived attributes of 4D BIM innovation, this time in relation to: 1. ‘the relative advantages of 4D BIM against construction planning functions’ (12 questions). 2. ‘relative advantages of 4D BIM against construction planning process' (7 questions) and 3. independent variables of 'compatibility'; 'complexity'; 'trialability'; and 'observability' (6 questions) of 4D BIM innovation. In this section, 5-point Likert scales were used to measure strength of agreement against the designed statements.

The final section of the questionnaire explored the 'communication channel preferences' for 'obtaining information' about 4D BIM and 'influencing decisions' about 4D BIM adoption or rejection decisions. This section also explored the 'types of innovation adoption or rejection decisions made'. There was an opportunity for the participants to add qualitative comments at the end of the questionnaire.

Appendix D-3 presents this research instrument in full. Additionally, **Appendix E-3** identifies the links between the question themes and the relevant literature for all key variables in this research instrument.

7.2 Results: Findings and Analysis

Unlike the analysis of the results from the exploratory questionnaire where descriptive statistics were presented then followed by various tests of statistical association, the analysis of the results from this questionnaire will integrate the analysis of univariate descriptive statistics (including measures of central tendency) with inferential statistical analysis undertaken at appropriate opportunities. All analyses were undertaken using the quantitative analyses tool IBM SPSS Version 22.

Analysis is presented under the following headings:

- Respondent profile.
- The characteristics of respondents organisations.

- Awareness and use of 4D BIM.
- Which characteristics explain user innovativeness?
- The rate of 4D BIM innovation adoption.
- The value of 4D BIM innovation.
- Assessing the perceived attributes of 4D BIM:
  - Assessing the relative advantages of 4D BIM against construction planning functions.
  - Assessing the relative advantages of 4D BIM against the construction planning process.
  - Assessing compatibility, complexity, trialability and observability.
- Decision types and communication preferences.
- Which variables determine the rate of 4D BIM innovation adoption?

7.3 Respondent Profile

Analysis of the responses to the profile questions helped to demonstrate that the data captured from the sample was representative of the targeted population, and that a normal distribution had been achieved. The research profile of the participants is presented in Table 7.1 below. In addition, several socioeconomic measures identified as important to IDT by Rogers (2003) were also recorded, although as explained below, these were subsequently found to be redundant for the purposes of this study.

Table 7.1: Profile of survey respondents

	N	Freq.	%	Range	Min.	Max.	Mean	Std. Dev
Gender	97		100.0					
▪ *Male*		*86*	*88.7*					
▪ *Female*		*11*	*11.3*					
Age	97			46	22	68	40.2	10.7
Highest level of education	97							
▪ *School leaver*		*1*	*1.0*					
▪ *Further education*		*17*	*17.5*					
▪ *Higher education (UG)*		*45*	*46.4*					
▪ *Higher education (PG)*		*34*	*35.1*					
Total Household Income (£GBP)	97							
▪ *Less than 25k*		*3*	*3.1*					
▪ *24,000 – 34,999*		*5*	*5.2*					
▪ *35,000 – 49,999*		*10*	*10.3*					
▪ *50,000 – 74,999*		*29*	*29.9*					
▪ *75,000 – 99,999*		*28*	*28.9*					
▪ *100,000+*		*22*	*22,7*					
Current Job Function	97		100.0					
▪ *Management Professional*		*47*	*48.5*					
▪ *Design Professional*		*5*	*5.2*					
▪ *Technical Specialist*		*45*	*46.4*					
Job level	97		100.0					
▪ *Upper Management (Strategy responsibility)*		*23*	*23.7*					
▪ *Middle Management (Tactical responsibility)*		*40*	*41.2*					
▪ *Lower Management (Day to day running)*		*34*	*35.1*					
Number of years worked in the construction industry	97			47	1	48	17.9	11.6
Year started working in the constructio industry	97			45	1969	2014	1996.7	11.7
Company Size (number of employees)	97		100.0					
▪ *Small (1-49)*		*19*	*19.6*					
▪ *Medium (50-249)*		*16*	*16.5*					
▪ *Large (250+)*		*62*	*63.9*					
Year company established	97			166	1848	2014	1951.9	50.6
Company BIM Maturity	97		100.0					
▪ *Level 0*		*10*	*10.3*					
▪ *Level 1*		*33*	*34.0*					
▪ *Level 2*		*43*	*44.3*					
▪ *Level 3*		*11*	*11.3*					

Q1 asked the respondents to confirm their sex and the data show that 88.7% (n = 86) of the participants were male and 11.3% (n = 11) of the participants were female. This distribution is largely consistent with data from the Office of National Statistics 2014 Labour Force Survey data reported upon by Knutt (2015) that indicated that: "*around 14%* [construction] *industry workers are female compared to 47% in the general workforce*[2]"

Q2 requested data on age in years, although one of Rogers (2003) key generalisations from his theory advises that "*Earlier adopters* [of an innovation] *are no different from later adopters in age"*. There was an age range of 46 years with the youngest respondent being 22 and the oldest respondent being 68. The mean was 40.21 and the median was 39.00 years old. Comparing mean age by sex gave similar distributions with the mean age of the male respondents being 40.65 years and the mean age of female respondents being 36.73 years old. Both groups recorded standard deviation of over 10 showing there was no real variation between these groups.

Socioeconomic data identified as important was collected across Q3–6. Per several key generalisations that Rogers (2003) makes in diffusion theory, attributes that make a difference in the rate of adoption of innovations and member innovativeness include measures recorded in this study of: 'wealth', 'highest level of education achieved' and 'social status'. For example, Rogers (2003) variously advises:

- *"Earlier adopters have more years of formal education than do later adopters"*
- *"Earlier adopters are more likely to be literate than are later adopters".*

2 The same article reports that at 14% the representation of women in the UK construction workforce is slightly higher than the EU average of 12%.

- *"Earlier adopters have higher social status than do later adopters"* - with 'occupation' (job function and job category), 'income' and 'total wealth' being advised as variables that equate to higher social status.

Such data were collected using various categorical response options, but with apologies to Rogers, no significant associations were found between these characteristics and individual user innovativeness as measured by confirmation of individual 4D BIM use (see section 7.7 for further details). In retrospect, gathering data for these socioeconomic measures was problematic and not as straightforward as Rogers (2003) suggests[3]. As such detailed analysis of responses to Q3 and Q4 are not presented individually here, other than to identify that Q3 requested the respondent to identify the highest level of education that they had achieved, and in response, 81.5% (n = 79) of respondents confirmed that they had studied at higher education level (HE) with 46.4% (n = 45) achieving undergraduate degree(s), and 35.1% (n = 34) having achieved some kind of post graduate qualification.

Details of job function (Q5) and job level (Q6) were recorded. Three available response options were provided along with descriptions in order for the respondents to categorise themselves. These response options for Q5 were:

- Management Professional (i.e. the primary function of this job role involves the direct management of people or processes and your management responsibilities may be at multi-project, individual project or individual site based levels).

3 For example, gathering data related to education (literacy and duration) was achieved via categorical variables identifying the highest level of formal education attained (Q3), however the 'recency' of such education was not recorded. Similarly, in contributing to social status, recording levels of income seems to provide an indicator, but these are likely determined by profession and geographical location. Ultimately income was recorded as total household income in GDP (Q4), against a range of pre-selected categories. As this potentially included the wealth of any spouse, this was deemed to be a less personal question than asking the respondents to disclose exactly what their salary was, as the researcher felt that wording the question in this manner would have resulted in a lower response rate.

- Design Professional (i.e. the primary function of this job role requires you to produce design information).
- Technical Specialist (i.e. the primary function of this job role is not the direct management of people, but management of a process or providing specialist technical advice or output. Examples include Planner/Design Manager/QS).

The highest proportion (48.5%; n = 47) of respondents identified themselves as 'Management Professionals', with 'Technical Professionals' accounting for the next highest proportion (46.4%; n = 45) and 'Design Professionals' accounting for only 5.2% (n= 5). In terms of job category (Q6) the data showed a fairly normal distribution where the majority of respondents identified themselves as middle management level (41.2%; n = 40), with lower management level being the next highest frequency (35.1%; n = 34), and upper management (23.7%; n = 23) being the least frequent response.

To help visualise these data, the stacked and panelled graph in Figure 7.1 shows the dispersion of household income (HHI) across both 'job function' and 'job level' and confirms that the highest proportions of upper management levels were 'managerial professionals', with 'technical specialists' more likely to be found in lower or middle management positions.

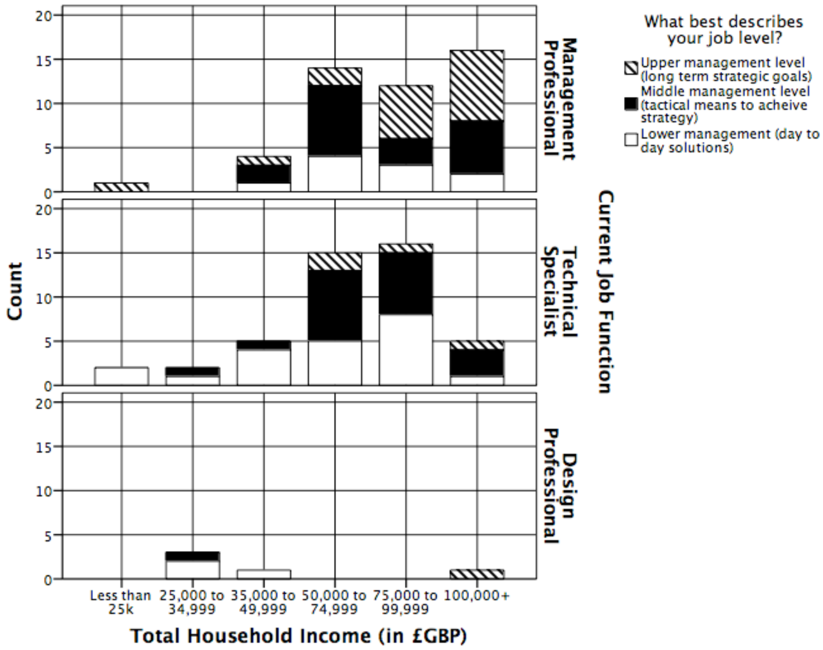

Figure 7.1: Job function and level vs Total household income (HHI)

Participant experience was recorded using two separate and straightforward measures, firstly by measured experience in 'number of years worked' (Q7) and then corroborating this data by recording the 'year started working in the industry' (Q8). In terms of number of years of experience working in the construction industry, there was a range of 47 years with the least experienced respondent having 1 year of experience, and the most experienced respondent (in terms of the number of working years) having 48 years of experience. The mean participant experience was revealed to be 17.87 working years. In terms of which year, they started working in the construction industry (Q8), the earliest commencing respondent advised that they started in 1969 and the latest commencing respondent advised that they started in 2014. The mean year of commencement was 1996. It is apparent that some of these data for Q7 and Q8 numbers are not quite correct when considered against each other (i.e. 2015 minus 48 years equals 1967 not 1969) as some respondents have approximated the date or number of years when responding, nonetheless, the data provided for these two measures does undoubtedly produce the linear relationship expected as illustrated in Figure 7.2. Outliers such as datapoint 22 (Respondent 170) and datapoint 83 (Respondent 230) could be explained as either having started and then having some time out from working in the industry (unemployment, study, family raising etc.) or simple miscalculation on behalf of the respondent.

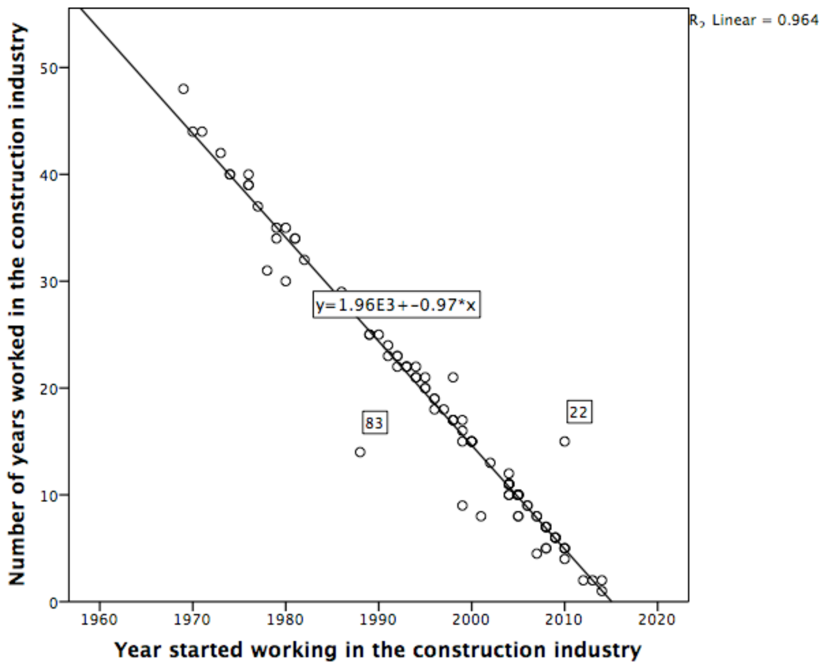

Figure 7.2: Year started working vs Number of years working in the construction industry

At this stage it is established that at individual level, the mean participant involved in this research could be expected to be male, of approximately 40 years of age who has studied at higher education level, and earns more than the UK national average salary, with a HHI of approximately £50,000 - £74,999. They have approximately 18 years of experience working in the construction industry, joined the industry sometime around 1997, and is typically a management professional operating within the types of middle management roles. This profile would correspond with the type of person identified as being directly responsible for determining project means and managing the solutions implemented by lower level staff, by researchers including Laufer and Tucker (1987); Ballard (1994); Winch and Kelsey (2005); and Crotty (2012).

7.4 The characteristics of respondents organisations

Three demographic-type questions were also asked to establish some information about the types of organisations that the respondents worked for. These questions related to 'company size', 'company maturity in terms of age', and 'reported organisational BIM maturity' in terms of perception of the BIM level that the company was operating at.

Q9 required the respondent to identify the 'size of the company' that they were then working for as measured by 'number of employees' (rather than financial measures such as profit or turnover). Inferential analysis of the results of the data from the previous exploratory questionnaire regarding company size (Sections 5.8 and 5.9) revealed that "*there was statistical significance in the relationship between company size and those companies that plan to implement BIM innovation. Larger companies of 250+ employees were much more likely to have already commenced implementing BIM Innovation than small (1-49) or medium (50-249) size organisations*, In this phase, a pattern repeated itself from the results of the earlier questionnaire in that the majority of respondents identified themselves as then working for a large company (250+ employees) with 63.9% (n = 62), the next largest proportion was respondents identified themselves as then working for a small company (1-49 employees) with 19.6% (n = 19) and the remaining 16.5% (n = 16) for medium-size enterprises.

Q10 attempted to determine organisational maturity. Laufer *et al*., (1994, pp 53-54) uses the term 'mature companies' to refer to companies that have consistently shown to perform productively and have "*well established* *management philosophies, advanced management systems and vast relevant experience including lessons learned by failures".* There could be many different measures of company maturity, but the design of this research chose simply to measure maturity by 'company age', that is to have the respondent confirm the year in which they had been established. To combat the 'recall-problem', the respondents were asked in the explanatory instructions of the survey to identify three key pieces of information prior to commencing the questionnaire, which included year of company establishment (the others will be identified at the appropriate juncture within this write up of results). Figure 7.3 show the results which identify a range of 166 years in company maturity as measured by age. The earliest year of establishment was 1848 and 22% (n = 21) of research participants recorded their companies as commencing in the 1800's. Across all sizes of company, the mean year of company establishment was 1952, the median year of establishment was 1965 and the data had a standard deviation of 50 years.

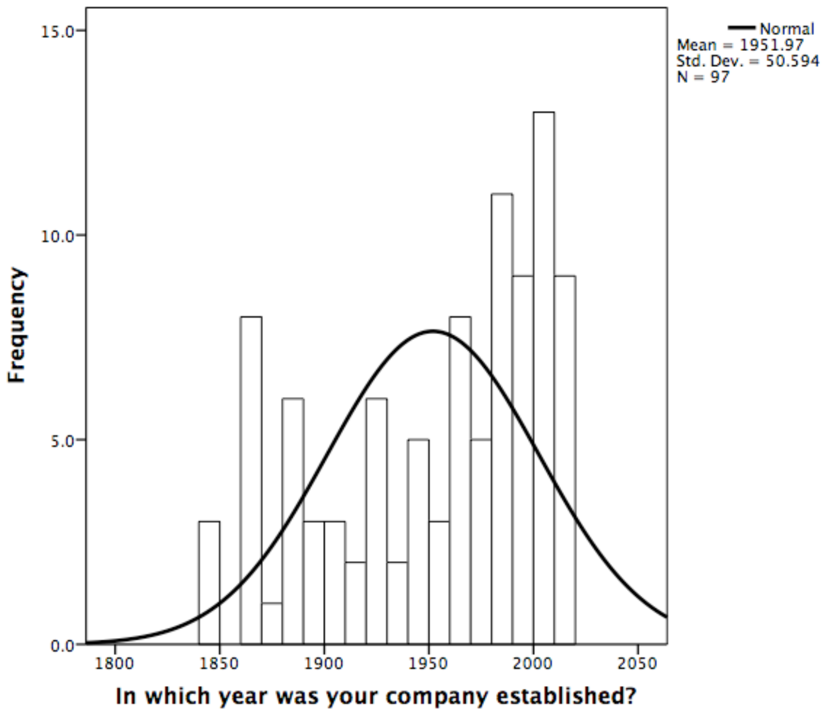

Figure 7.3: Company maturity in age as determined by year established.

However, it may be better to consider company maturity against each separate category of company age. This data can be better visually communicated in a few ways such as making use of box plots in Figure 7.4 to indicate the central tendency and dispersion for each company in terms of size and age. For large organisations, the median recorded age of company establishment was 1946, for medium sized organisations the median recorded age of company establishment was 1986, and for smaller organisations the median recorded age of company establishment was 2004.

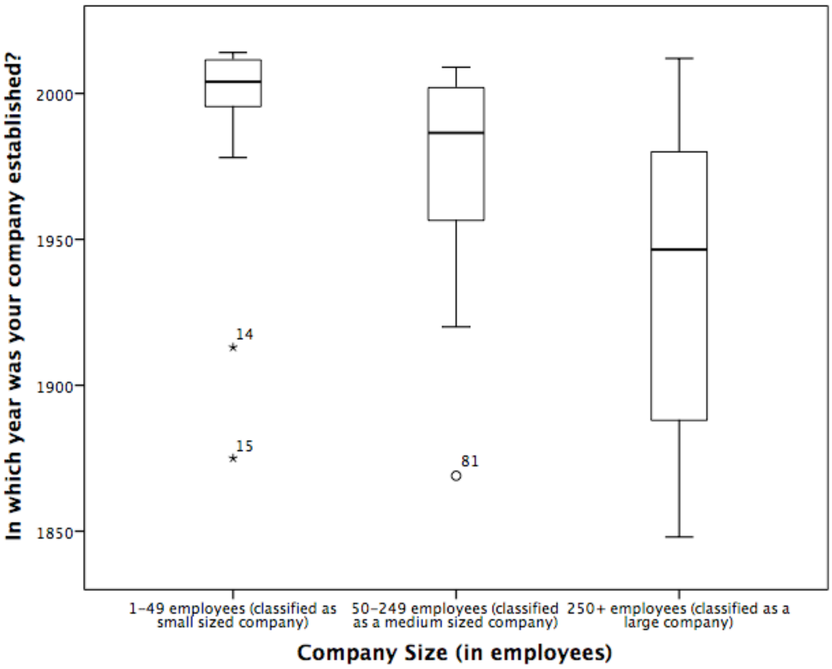

Figure 7.4: Box-plots of company sizes vs maturity in age as measured by individual years established

To help further visualise the impact of the time horizon, the data for individual company maturity as recorded by age was recoded and grouped into decades. The next graph shows a relationship between the number of organisations established in each decade and their current size as reported in 2015. Both figures 7.4 and 7.5 illustrates that older companies i.e. those which have been established from the 1840's–1990's are more likely to now be larger companies of 250+ persons whilst younger companies i.e. those established in the 15-year date range between 2000–2015 are more likely to be a small company of (1-49 persons) than any other size.

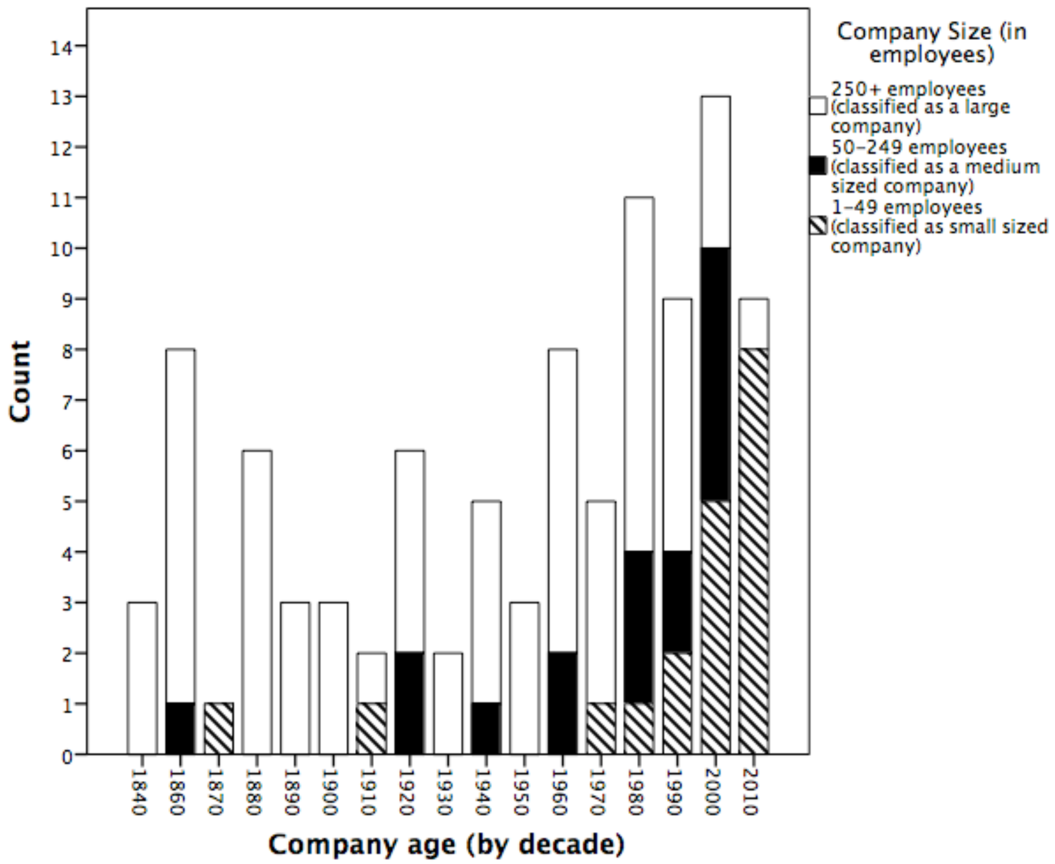

Figure 7.5: Company sizes vs maturity in age as measured by decades established

In Q11, the respondents' perception of their organisations BIM maturity was assessed by providing comprehensive definitions of the various BIM levels as devised by the NBS (2014a) along with the BIM maturity wedge (BIWG, 2011) and asking the respondent to use these artefacts to identify where the current BIM maturity level of their company was. Figure 7.6 shows that 44.3% (n = 43) of respondents assessed their companies' BIM maturity at Level 2, and 34.0% (n = 33) at Level 1; 11.3% (n = 11) assessed their companies' BIM maturity at Level 3 and 10.3% (n = 10) at Level 0.

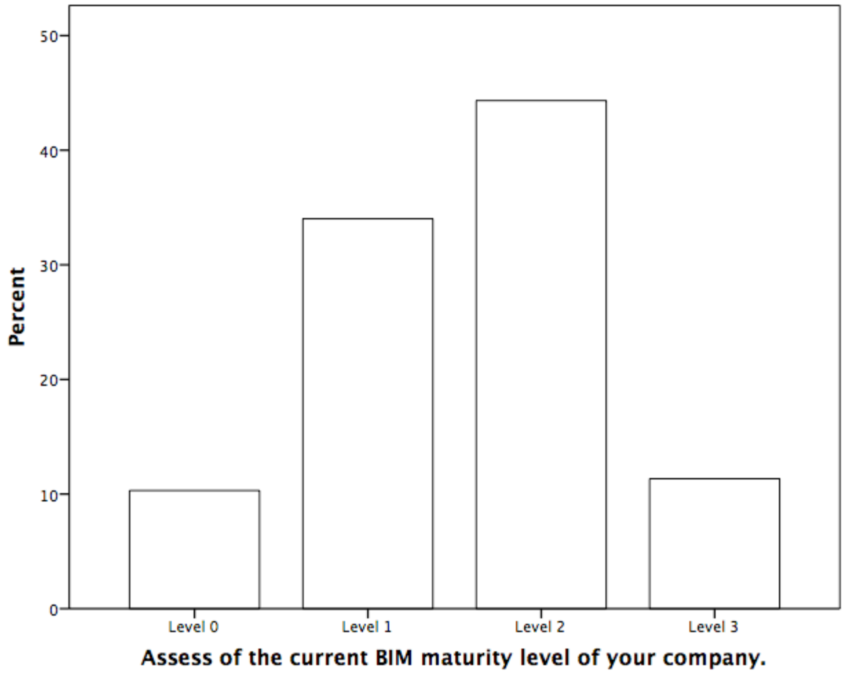

Figure 7.6: Respondents 2015 assessment BIM level categorisation of their organisation

This question was a repeat of a question from the initial exploratory survey taken in 2013-2014 where 52.9% (n = 72) assessed their companies' BIM maturity at Level I, and 30.8% (n = 42) at Level II+. It is also interesting to note that in a separate question in that same survey a majority of respondents (62.5%; n = 85) predicted that by 2016 their company would meet the Level II requirements with both 16.9% (n = 23) equally believing that they would be in either the Level I or Level III category.

The previous questionnaire allowed analysis of statistical associations in the relationship between company size and reported organisational BIM Maturity (see sections 5.4–5.5) and found that "*there was no statistical significance in the relationship between company size and reported organisational BIM Maturity*". However, because the second explanatory survey included these questions again, there was further data to be able to retest this relationship. The same null (H_0) and alternative (H_A) hypotheses were formulated for this test:

H$_0$: There is no relationship between company size and reported organisational BIM Maturity.

H$_A$: There is a relationship between company size and reported organisational BIM Maturity.

Company Size (in employees) * What is the BIM Maturity of your company? Crosstabulation

			What is the BIM Maturity of your company?			
			Level 0	Level 1	Level 2+	Total
Company Size (in employees)	1-49 employees (classified as small sized company)	Count	4	7	8	19
		% of Total	4.1%	7.2%	8.2%	19.6%
	50-249 employees (classified as a medium sized company)	Count	5	6	5	16
		% of Total	5.2%	6.2%	5.2%	16.5%
	250+ employees (classified as a large company)	Count	1	20	41	62
		% of Total	1.0%	20.6%	42.3%	63.9%
Total		Count	10	33	54	97
		% of Total	10.3%	34.0%	55.7%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	17.199[a]	4	.002	.002		
Likelihood Ratio	17.123	4	.002	.002		
Fisher's Exact Test	16.840			.001		
Linear-by-Linear Association	9.575[b]	1	.002	.002	.002	.001
N of Valid Cases	97					

a. 2 cells (22.2%) have expected count less than 5. The minimum expected count is 1.65.

b. The standardized statistic is 3.094.

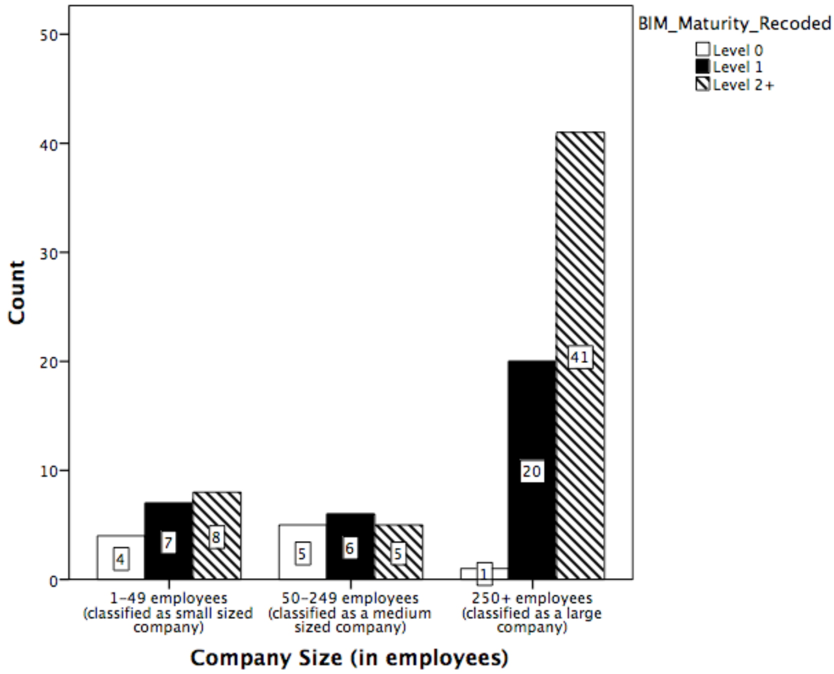

Figure 7.7: Tests of association: Company size against reported organisational BIM maturity

In this test, all 97 cases were usable[4]. A Fisher's Exact Test gave the statistic of .001 (the previous test statistic was .051) This time H_0 can be rejected in favour of H_A, meaning: *There is a relationship between company size and reported organisational BIM Maturity*. Further examination of the data produced in the cross-tabulation about this relationship appears to suggest that larger companies are now more likely to report that they have greater organisational BIM maturity.

At this stage, it can also be established that the mean organisation that the typical '40-year-old middle management' participant involved in this research could be expected to be from is a large company of 250+ employees that was established somewhere between 1946-1965 and that has a BIM organisational maturity of level 2. This concludes the analysis of the data associated with the respondent's profile

4 In all tests of association where conditions for X2 were not met because of any expected counts being less than 5, the Fisher's Exact Test was used.

7.5 Awareness and use of 4D BIM

Several questions were designed to obtain information related to 'timing' and 4D BIM. Specifically, these related to: 'timing of first awareness'; 'confirmation, or awareness of use'; and 'timing of first adoption'. Statistical analysis undertaken in this section included: making use of responses from demographic type questions to determine characteristics that explain user innovativeness; and using reported data of the years of 'first awareness', and 'first use', to explore the rate of adoption of 4D BIM innovation.

Q12 asked '*In which year did you first become aware of 4D BIM?'* This question related to the first stage of Rogers (2003) Innovation-decision process model which is concerned with aspects of innovation knowledge. In the literature review it was found that the origins of 4D could be traced back to the work of Martin Fischer and CIFE in 1986/87 (Rischmoller and Alarcon, 2002) so it was of interest to see the respondents' earliest awareness of 4D. There was a range of 17 years between the earliest year of awareness in 1998 and the latest awareness of a respondent of 2015. The mean year of awareness was 2009 and the median year of awareness was 2011. Most the respondents fell within the date range of 2002–2015 although three outliers demonstrate awareness earlier than this. With regards to these outliers 'datapoint 6' (Respondent 53) is interesting as this person had the earliest recorded awareness of 1998 but did not adopt until 2005 and then only because of a 'company (authority) decision'[5]. 'Datapoint 84' (Respondent 221) was also interviewed in the semi-structured interviews, and recalled that this early awareness was because of postgraduate study at Salford University under the teaching of academic/former CIOB

5 See section 7.10 for analysis of decision types

president Ghassan Aouad. There is no means of determining why 'datapoint 22' (Respondent 170) was also an outlier in terms of earlier awareness.

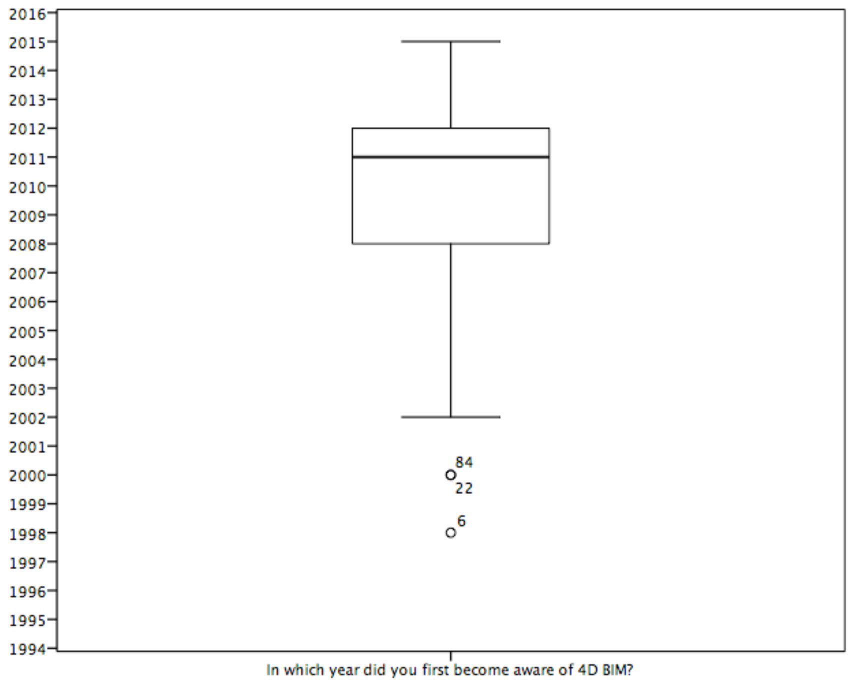

Figure 7.8: Respondents first recorded awareness of 4D BIM

Q13 asked '*What was your first impression of 4D BIM?'* This question also related to the Rogers (2003) Innovation-decision process model particularly the second stage of innovation 'persuasion' which occurs when a decision-making unit "*forms a favourable or unfavourable attitude toward the innovation*". Ordinal responses were received on a 5 point Likert scale with response options ranging from 1 = '*Very unfavourable'* to 5 = '*Very favourable*' with a middle response option (3) offering a '*neutral*' category. 73.0% (n = 81) of the participants had a favourable first impression to 4D BIM innovation with the mean response being 3.87 and the median response being 4.00 out of 5.00.

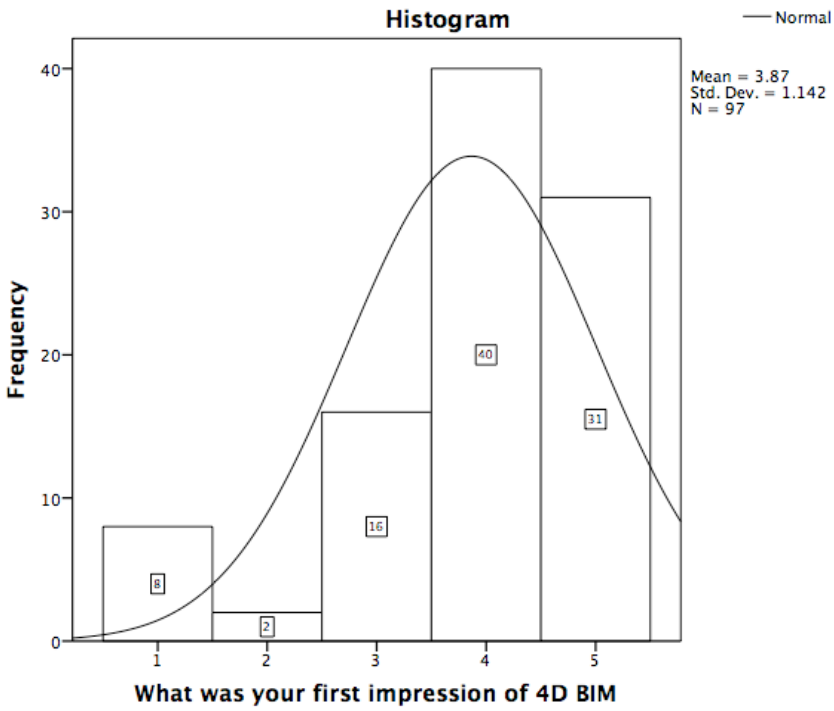

Figure 7.9: First impressions of 4D BIM innovation

Q14 asked *'Do you currently use 4D BIM in your construction planning practices?'* 51.5% (n = 50) of the total respondents confirmed use. The designed logic of the questionnaire then directed respondents who answered 'NO' to Q16 which asked '*Are you aware of anyone in your organisation who currently uses 4D BIM in their construction planning practices*?' 11.3% of the total respondents (n = 11) confirmed use, meaning 62.8% (n = 61) of respondents use/or were aware of someone in their organisation that uses 4D BIM innovation. The remaining 37.2% (n = 36) do not use, and were not aware of anyone in their organisation that uses it.

The data analysed so far provides an opportunity to test for any statistical associations between the second stage of Rogers (2003) Innovation-decision process 'persuasion' compared against personal use of 4D BIM Innovation. Competing null (H_0) and alternative (H_A) hypotheses were formulated for this test:

H_0: There is no relationship between the first impressions formed about 4D BIM innovation and personal use of 4D BIM Innovation.

H_A: There is a relationship between the first impressions formed about 4D BIM innovation and personal use of 4D BIM Innovation.

Do you currently use 4D BIM in your construction planning practices? * What was your first impression of 4D BIM? Crosstabulation

			What was your first impression of 4D BIM?			
			Unfavourable	Neutral	Favourable	Total
Do you currently use 4D BIM in your construction planning practices?	Yes	Count	6	3	41	50
		% of Total	6.2%	3.1%	42.3%	51.5%
	No	Count	4	13	30	47
		% of Total	4.1%	13.4%	30.9%	48.5%
Total		Count	10	16	71	97
		% of Total	10.3%	16.5%	73.2%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	8.269[a]	2	.016	.015		
Likelihood Ratio	8.759	2	.013	.017		
Fisher's Exact Test	8.314			.015		
Linear-by-Linear Association	1.176[b]	1	.278	.291	.177	.068
N of Valid Cases	97					

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 4.85.

b. The standardized statistic is -1.084.

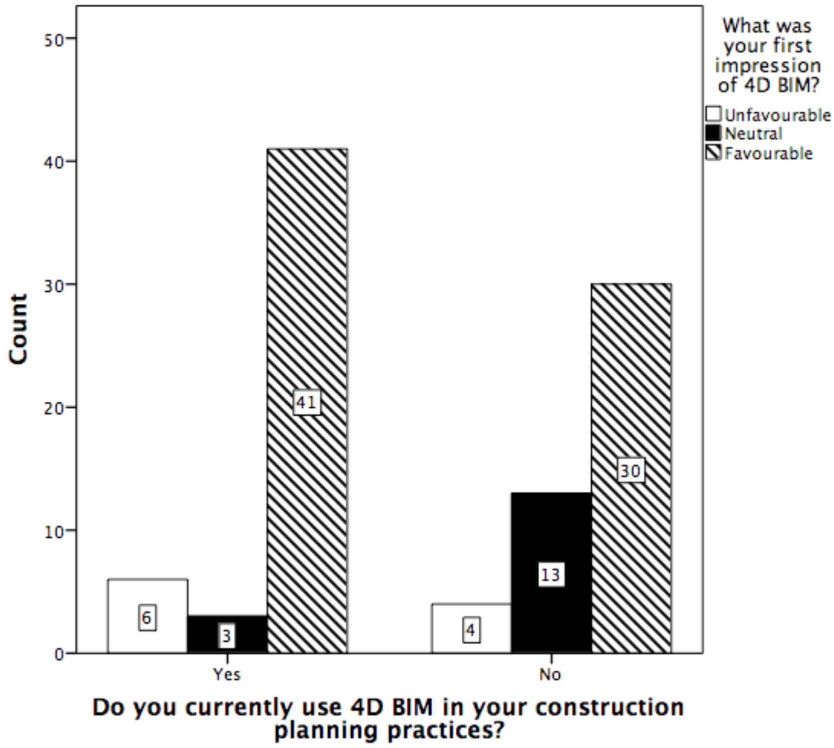

Figure 7.10: Tests of association: First impressions against personal use of 4D BIM innovation

To run this test response options had to be recoded within SPSS so that the 'Very Favourable' and 'Favourable' options were recoded as 'Favourable' and the 'Very Unfavourable' and 'Unfavourable' response options were recoded as 'Unfavourable'. In this test, all 97 cases were useable. A Fisher's Exact Test gave the statistic of .015 meaning that H_0 could be rejected in favour of H_A: *There **is** a relationship between the first impressions formed about 4D BIM innovation and personal use of 4D BIM Innovation. Further examination* of the data produced in the cross-tabulation appears to suggest that there is more likely to be subsequent personal use of 4D BIM innovation if an initial favourable impression is formed.

7.6 Which characteristics explain user innovativeness?

By now there was data available to address Research Objective 4.3: 'explore and explain the innovativeness of members of this construction social system'. This was done by using results from the general demographics questions along with the above results of Q14, which confirmed personal use of 4D BIM innovation. Several of the independent demographic categorical variables (‘education’, ‘HHI’, ‘job function’, ‘job level’, ‘company size’, ‘reported organisational BIM maturity’) could be tested against the categorical variable used for ‘confirmation of 4D BIM use’, meaning that Chi-square or Fishers Exact tests could be used to test for these associations:

- Highest level of education achieved *against* use of 4D BIM innovation.
- Total Household Income (as an indicator of social status) *against* use of 4D BIM innovation.
- Job function (as an indicator of social status) *against* use of 4D BIM innovation.
- Job level (as an indicator of social status) *against* use of 4D BIM innovation.
- Company size *against* use of 4D BIM innovation.
- Reported organisational BIM Maturity *against* use of 4D BIM innovation.

In each test, appropriate null (H_0) and alternative (H_A) hypotheses were formulated. As noted earlier, no significant associations were found in the tests involving the socioeconomic measures of ‘education’, ‘HHI’ and ‘social status’. Significant associations were however found in the tests involving ‘company size’ *against* ‘use of 4D BIM innovation’ *and* ‘reported organisational BIM Maturity’ *against* ‘use of 4D BIM innovation’.

In the previous exploratory study, relationships between company size and organisational use of 4D BIM Innovation were explored, and it was found that there was no relationship between company size and company use of 4D BIM Innovation. This explanatory survey asked a different question: *Do **you** currently* *use 4D BIM in your construction planning practices?* Competing null (H_0) and alternative (H_A) hypotheses were formulated for this test:

H_0: There is no relationship between company size and personal use of 4D BIM Innovation.

H_A: There is a relationship between company size and personal use of 4D BIM Innovation.

Crosstab

			Do you currently use 4D BIM in your construction planning practices?		Total
			Yes	No	
Company Size (in employees)	1-49 employees (classified as small sized company)	Count	10	9	19
		% of Total	10.3%	9.3%	19.6%
	50-249 employees (classified as a medium sized company)	Count	2	14	16
		% of Total	2.1%	14.4%	16.5%
	250+ employees (classified as a large company)	Count	38	24	62
		% of Total	39.2%	24.7%	63.9%
Total		Count	50	47	97
		% of Total	51.5%	48.5%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	12.133[a]	2	.002	.002		
Likelihood Ratio	13.273	2	.001	.002		
Fisher's Exact Test	12.508			.002		
Linear-by-Linear Association	2.178[b]	1	.140	.164	.089	.034
N of Valid Cases	97					

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.75.

b. The standardized statistic is -1.476.

Figure 7.11: Tests of association: Company size against personal use of 4D BIM

In this test, all 97 cases were usable. Conditions for Chi-Square (X^2) were met and a test statistic of .002 was given meaning that H_0 could be rejected in favour of H_A: *There **is** a relationship between company size and personal use of 4D BIM innovation.* Further examination of the data produced in the cross-tabulation appears to suggest that there is more likely to be personal use of 4D BIM innovation within larger companies.

To test associations between reported organisational BIM Maturity compared against personal use of 4D BIM Innovation. Competing null (H_0) and alternative (H_A) hypotheses were formulated for this test:

H_0: There is no relationship between reported organisational BIM maturity and personal use of 4D BIM Innovation.

H_A: There is a relationship between reported organisational BIM maturity and personal use of 4D BIM Innovation.

Assess of the current BIM maturity level of your company. * Do you currently use 4D BIM in your construction planning practices? Crosstabulation

			Do you currently use 4D BIM in your construction planning practices?		
			Yes	No	Total
Assess of the current BIM maturity level of your company.	Level 0	Count	0	10	10
		% of Total	0.0%	10.3%	10.3%
	Level 1	Count	12	21	33
		% of Total	12.4%	21.6%	34.0%
	Level 2	Count	28	15	43
		% of Total	28.9%	15.5%	44.3%
	Level 3	Count	10	1	11
		% of Total	10.3%	1.0%	11.3%
Total		Count	50	47	97
		% of Total	51.5%	48.5%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	23.678[a]	3	.000	.000		
Likelihood Ratio	28.796	3	.000	.000		
Fisher's Exact Test	24.954			.000		
Linear-by-Linear Association	23.246[b]	1	.000	.000	.000	.000
N of Valid Cases	97					

a. 1 cells (12.5%) have expected count less than 5. The minimum expected count is 4.85.

b. The standardized statistic is -4.821.

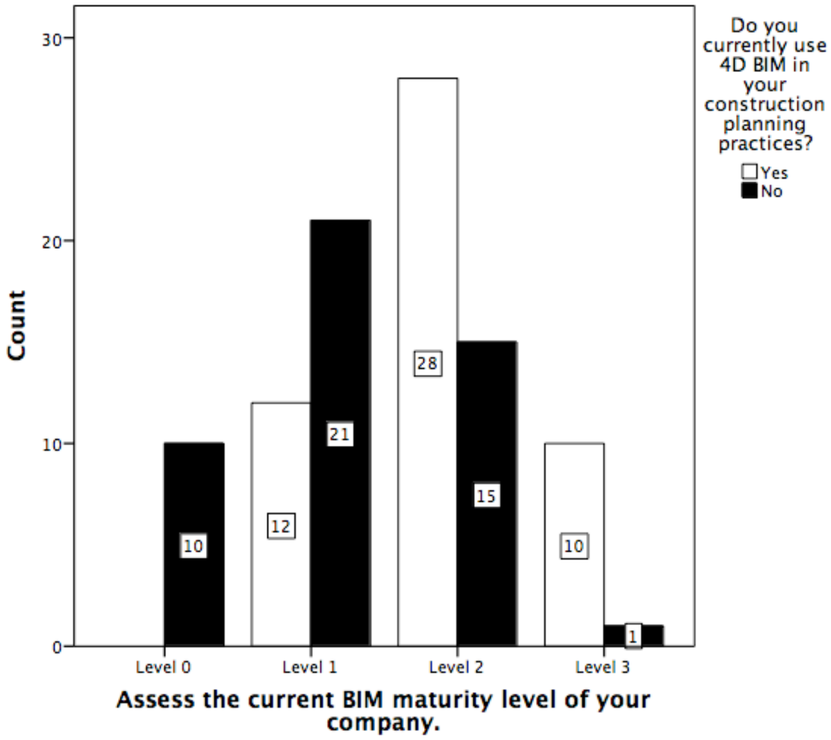

Figure 7.12: Tests of association: Reported organisational BIM Maturity against personal use of 4D BIM

In this test, all 97 cases were usable. A Fisher's Exact Test gave the statistic of .000 meaning that H_0 could be rejected in favour of H_A: *There is a relationship between reported organisational BIM maturity and personal use of 4D BIM Innovation.* Interrogation of the data produced in the cross-tabulation appears to suggest that the higher the perception of organisational BIM maturity, the more likely that personal use of 4D BIM innovation will occur.

These two results partially satisfied research objective 4.3: 'explore and explain the innovativeness of members of this construction social system'.

7.7 The rate of 4D BIM innovation adoption

The sub-set of respondents who had self-identified as adopters, were asked to identify the year in which they adopted 4D BIM in their construction planning practices for the first time (Q15). The earliest year of adoption was revealed to be 2002, the mean year was 2011 and the median year was 2013. Unstructured interviews with 'datapoint 40' (Respondent 188), the outlier shown as the earliest adopting respondent, revealed involvement as an industry practitioner in a previous 4D research project known as VIRCON[i] which produced research outputs on various planning related benefits including the development of the CSA planning technique (Dawood *et al*., 2002; North and Winch, 2002; Heesom and Mahdjoubi, 2002; 2004) discussed earlier in the literature review (see section 2.2.10).

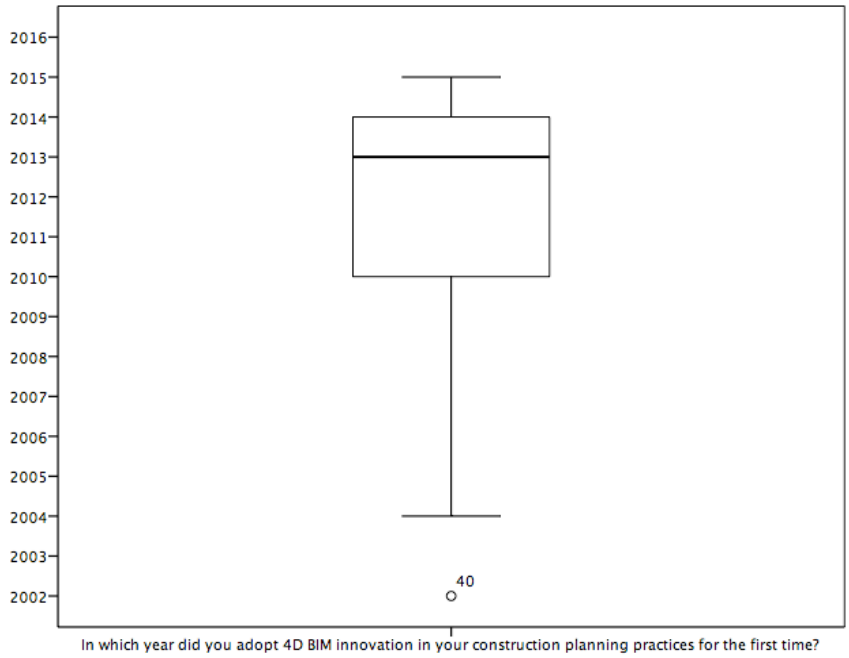

Figure 7.13: Identified year of first use of 4D BIM innovation by self-identified adopters.

For purposes of completeness it is worth also reviewing the identified year of first use of other users of 4D BIM as provided by respondents who do not themselves use 4D BIM innovation (*no question number provided as this question was only* *presented if respondents answered 'NO' to Q15 within the design logic of the questionnaire*). The earliest year of adoption was assumed to be 2010, the mean year was assumed to be 2012 and the median year was assumed to be 2013.

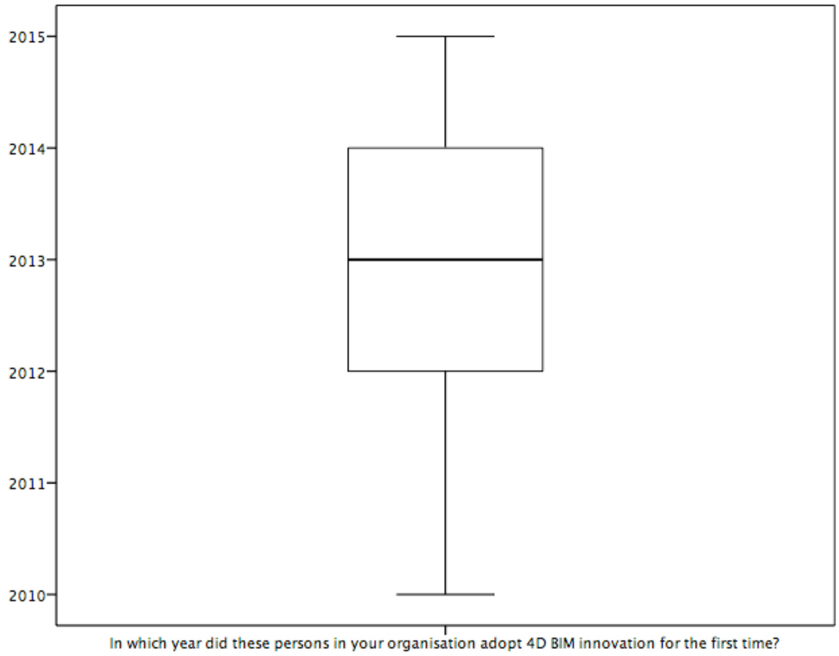

Figure 7.14: Identified first use of other users of 4D BIM innovation as provided by questionnaire respondents.

Looking at 'year of first awareness' vs. 'year of first use (adoption) only' for respondents who self-identified as adopters, the Pearson's Correlation for these two measures at .764 confirms what can be described as *a "strong positive relationship"* (Cohen and Holliday, 1982, as cited by Bryman and Cramer, 2011) and the 2-tailed statistic is .000 which is significant at the 0.01 level. The coefficient of determination (R2 Statistic) is 0.583 as shown in Figure 7.15. Which meant that more than half (58.3%) of the variance in the timing of first adoption could be attributed to the timing of first awareness, however it also meant that less than half (41.7%) of the variance in the timing of first adoption was due to variables other than the timing of first awareness. The other classic diffusion variables that may determine the rate of adoption of 4D BIM innovation are considered elsewhere in this results section.

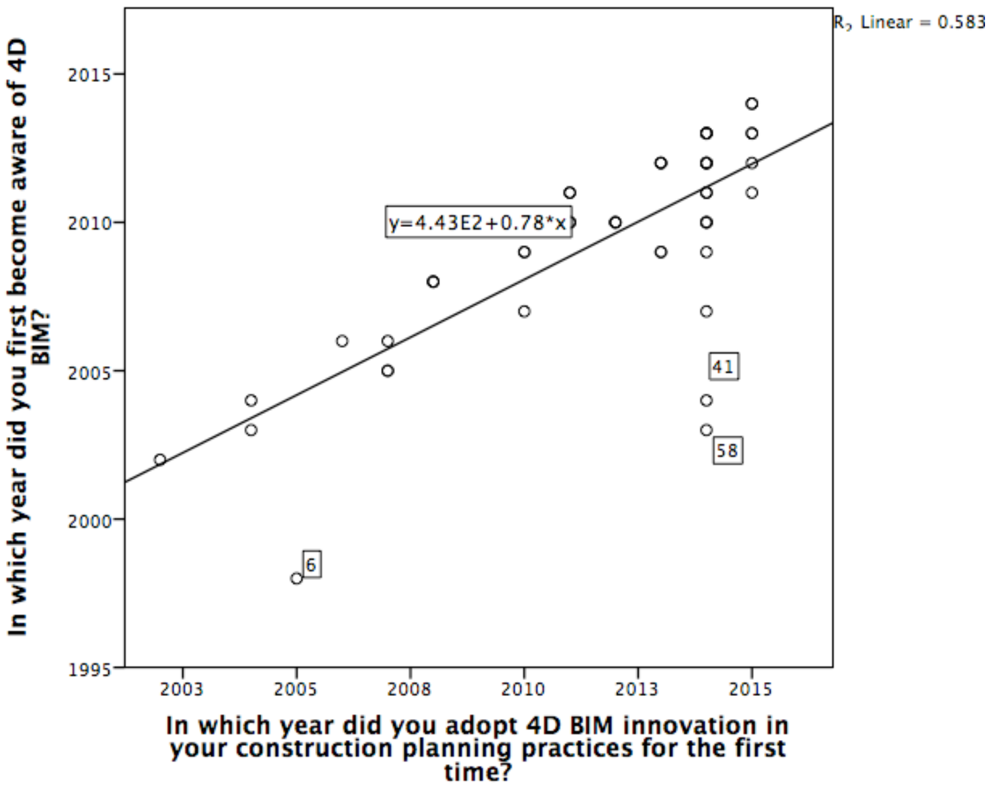

Figure 7.15: Year of awareness vs. year of adoption for respondents self-identifying as adopters.

Analysis also revealed a handful of interesting outliers all of whom then worked for large contracting organisations of 250+ employees. As reported above, the earliest recorded awareness of 4D BIM in this sample was respondent 6 who first became aware in 1998 but did not adopt until 2005 and then only because of a ‘company (authority) decision’. The longest period between awareness and adoption was observed in respondent 58 who first became aware in 2003 but did not adopt until 2014, a lag of 11 years and whose adoption was described as a ‘collective-decision’. Respondent 41 was a similar outlier who first became aware in 2004 but did not adopt until 2014, a lag of 10 years and adoption was described as an ‘authority-decision’ (decision types are more fully explored in section 7.10). Whilst these individual data points could be isolated to argue the slow diffusion of technological process based innovations in the construction industry, the usual time lag recorded between awareness and adoption is confirmed as being between 2.38–3.00 years (28.5–36.0 months). This result partially satisfies research objective 4.4: 'explore and explain the rate of adoption of 4D BIM innovation'.

7.8 The value of 4D BIM innovation

Q16, a repeated question from the earlier exploratory survey, asked the respondents 'Please indicate the level of value that you now believe 4D BIM adds or would add to your business'. Like Q13, ordinal responses were received on a 5 point Likert scale with response options ranging from 1 = 'No Value' to 5 = 'High Value' although in this question the middle response option was not a neutral category and instead meant that the respondent believed 4D BIM innovation to add medium value. 69.0% (n = 67) of the participants perceived 4D BIM innovation to add a high level of value to their business with level 4 scoring 38.0% (n = 37) level 5 scoring 31.0%. (N = 30), the mean response being 3.84 and the median response being 4.00 out of 5.00.

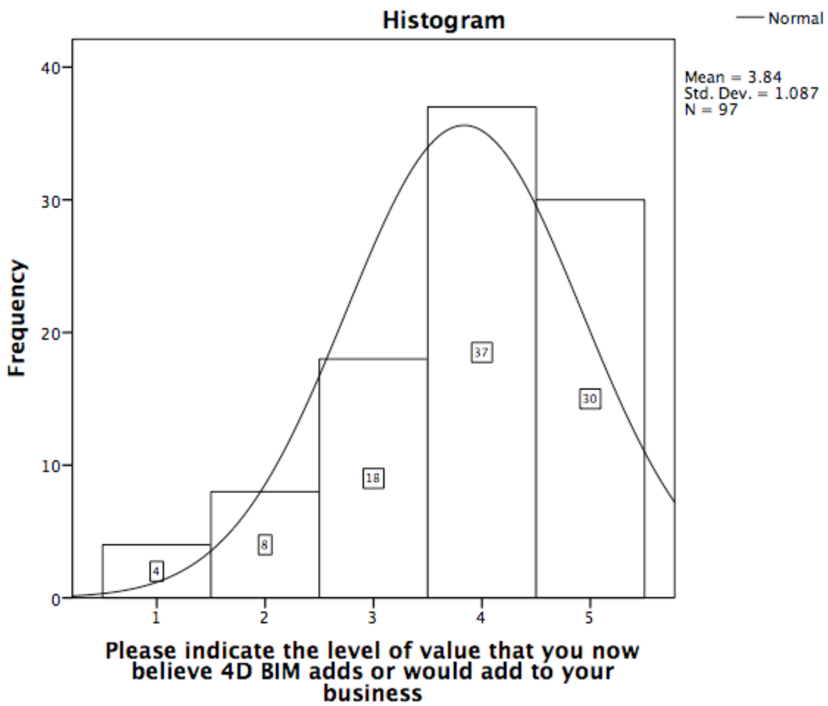

Figure 7.16: Perception of value of 4D BIM innovation in 2015

This question was also a repeat of a question from the initial exploratory survey taken in 2013-2014 and the results remained consistent with most respondents (67.7%; n = 92) agreed that 4D BIM Innovation would add high value to their business with level 4 scoring 35.3% (n = 48) and level 5 scoring 32.4%. (N = 44), the mean and median scores were 3.79 and 4.00 respectively. Inferential analysis of the data from the previous exploratory questionnaire also focussed on exploring the relationship between company size and perception of the level of value that 4D BIM innovation would add to their business, and found that; "*there was no statistical significance in the relationship between company size and the perceived value of 4D BIM innovation, where regardless of size all companies perceived there to be high value in the use 4D BIM innovation*" (see details of Test 4 in Sections 5.4–5.5). Again, because the second explanatory survey included these questions again, there was further data to be able to retest this relationship. The same null (H_0) and alternative (H_A) hypotheses were formulated for this test:

H_0: There is no relationship between company size and the perceived value of 4D BIM innovation.

H_A: There is a relationship between company size and the perceived value of 4D BIM innovation.

Company Size (in employees) * Please indicate the level of value that you now believe 4D BIM adds or would add to your business Crosstabulation

			Please indicate the level of value that you now believe 4D BIM adds or would add to your business					
			1	2	3	4	5	Total
Company Size (in employees)	1-49 employees (classified as small sized company)	Count	0	2	1	10	6	19
		% of Total	0.0%	2.1%	1.0%	10.3%	6.2%	19.6%
	50-249 employees (classified as a medium sized company)	Count	3	1	3	5	4	16
		% of Total	3.1%	1.0%	3.1%	5.2%	4.1%	16.5%
	250+ employees (classified as a large company)	Count	1	5	14	22	20	62
		% of Total	1.0%	5.2%	14.4%	22.7%	20.6%	63.9%
Total		Count	4	8	18	37	30	97
		% of Total	4.1%	8.2%	18.6%	38.1%	30.9%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	14.162[a]	8	.078	.075		
Likelihood Ratio	11.940	8	.154	.211		
Fisher's Exact Test	10.471			.177		
Linear-by-Linear Association	.011[b]	1	.916	.954	.487	.046
N of Valid Cases	97					

a. 8 cells (53.3%) have expected count less than 5. The minimum expected count is .66.

b. The standardized statistic is -.106.

Figure 7.17: Tests of association: Company size against perceived value of 4D BIM innovation

In this test, all 97 cases were useable. A Fisher's Exact Test gave the statistic of .177 (the previous test statistic was .124) meaning again that H_0 could not be rejected.

Attention now turns to the series of independent variables that further help to explain the rate of adoption of 4D BIM innovation. The following sections will look at the questions and analysis of the data that relate to the perceived attributes of

4D BIM innovation, the types of innovation decision made and communication channels.

7.9 Assessing the perceived attributes of 4D BIM

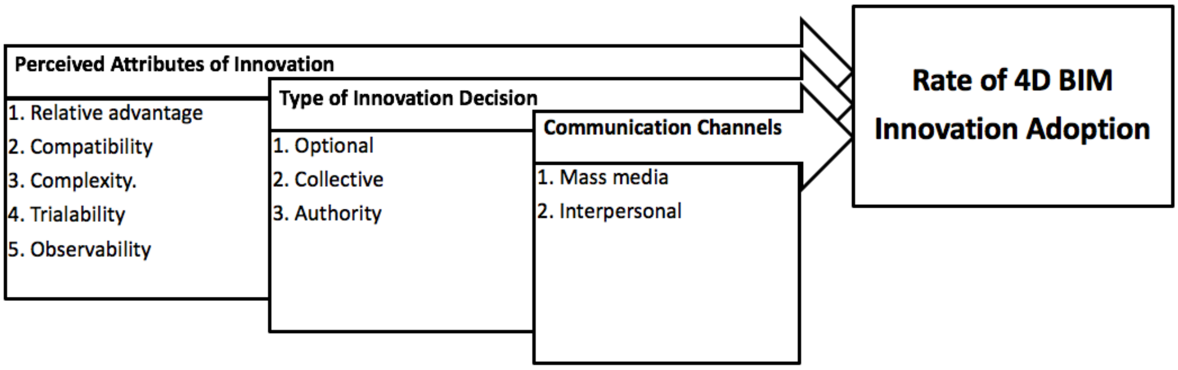

Figure 7.18: Variables determining the rate of 4D BIM innovation adoption. For reference, identical to Figure 6.2

Analysis now turns to those independent variables which may further explain the rate of adoption of 4D BIM. The questionnaire provided a series of statements in relation to the perceived attributes of 4D BIM which included the relative advantages' of 4D BIM against 'construction planning functions' (i.e. the required outcomes of the planning process) and, the 'relative advantages' of 4D BIM against 'construction planning process' (i.e. the things that planners do when they plan) as well as IDT constructs of 'compatibility', 'complexity', 'trialability' and 'observability'. To assess such perceptions, ranking type questions using a 5-point Likert scale to measure strength of agreement were included to gather ordinal responses. Response options ranged from 1 = 'Strongly disagree' to 5 = 'Strongly agree' with a middle response option (3) offering the 'neutral' option. The question construction of the relative advantage type questions all followed the same pattern of "*In general, the use of 4D BIM would be more effective _____ (Insert category of use) ______ than our current practices", (Q20–37)* however this pattern was not strictly followed for the 'compatibility', 'complexity', ‘trialability’ and ‘observability’ questions (Q38 - 43), although 5-point Likert scales with the same response options were still used. The online version of these sections of the questionnaire randomised these questions, along with the response options positioning in an attempt to minimise the use of response sets by the participants.

7.9.1 Assessing the relative advantages of 4D BIM against construction planning functions

All questions statements in this section focussed on the various functions of construction planning, identified from a review of the construction planning literature. These can be summarised as: (A) ‘work winning’; (B) ‘design interrogation’; (C) ‘planning construction methods’; (D) ‘visualising the construction process’; (E) ‘facilitating understanding of the construction process’; (F) ‘validating the time schedule’; (G) ‘location based planning’; (H) ‘progress reporting’; (I) ‘site layout planning (positions)’; (J) ‘logistics planning (movements)’; (K) ‘communicating working space’; and (L) ‘safety planning’. Within virtual construction, usage of these categories was also confirmed in the analysis of the data from the exploratory questionnaire. Because of the large number of questions, and the similarity of the charts that would be used to present the results, only data with the single highest and two joint lowest scoring relative advantages are presented.

Results from the previous exploratory questionnaire had indicated a high level of BIM awareness and some experience of use of 4D BIM innovation, particularly for work winning which was the highest scoring option in a question that compared categories of virtual construction use. The purpose of Q19 was to understand the degree of relative advantage that 4D BIM offered in this area and it was worded as follows: ‘*In general, the use of 4D BIM would be more effective* *in work winning activities than our current practices'.* 68.1% (n = 66) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.91 and the median response being 4.00 out of 5.00

Q20 was worded '*In general, the use of 4D BIM would be more effective for interrogating design than our current practices*' and 82.4% (n = 80) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 4.08 and the median response being 4.00 out of 5.00

Q21 was worded '*In general, the use of 4D BIM would be more effective in planning construction methods than our current practices'.* The results of the previous questionnaire had also indicated a high level of BIM awareness, and some experience of 4D BIM use, particularly for methods planning which was the second highest scoring category. 79.4% (n = 77) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 4.06 and the median response being 4.00 out of 5.00.

Q22 was worded '*In general, the use of 4D BIM would be more effective in visualising the construction process than our current practices'.* In the results of the previous questionnaire, the ability to visualise construction process had been the highest scoring option within the *4D offers a significant improvement'* category for a question that that compared both traditional and 4D planning against aspects of the planning process. In this research, it was again the highest scoring function where 91.8% (n = 89) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 4.37 and the median response being 5.00 out of 5.00.

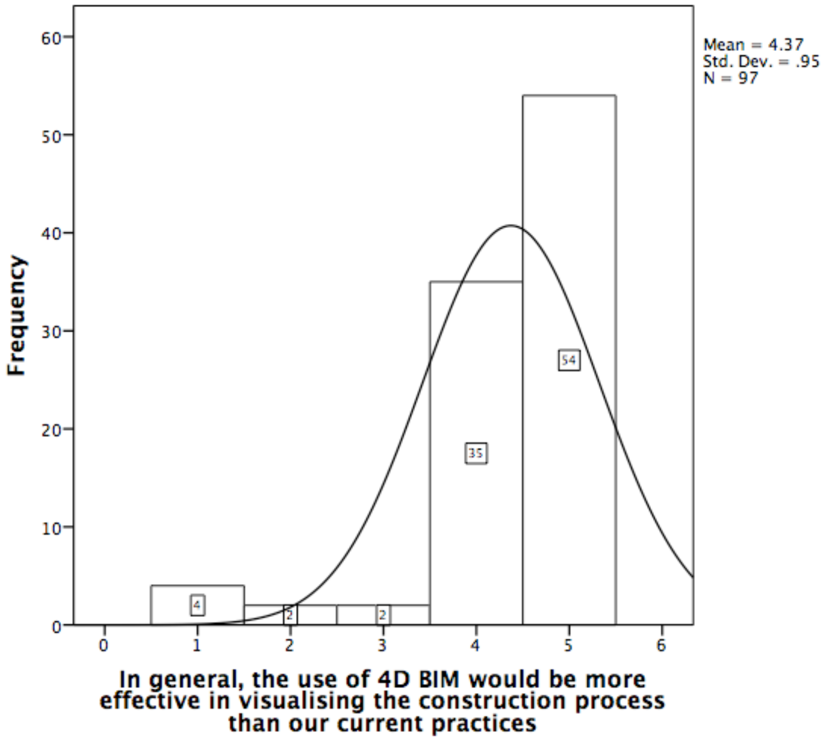

Figure 7.19: Relative advantage of visualising the construction process using 4D BIM innovation

Q23 was worded '*In general, the use of 4D BIM would be more effective in facilitating understanding of the construction process than our current practices'.* In the results of the previous questionnaire the ability to facilitate understanding of the construction process had been the second highest scoring option within the *4D offers a significant improvement'* category in a question that that compared both traditional and 4D planning against aspects of the planning process. In this research, it was again the second highest scoring function where 87.6% (n = 85) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 4.27 and the median response being 4.00 out of 5.00.

Q24 was worded '*In general, the use of 4D BIM would be more effective in validating the time schedule than our current practices'.* 77.3% (n = 85) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.90 and the median response being 4.00 out of 5.00.

The data gathered from the next two questions offered the joint lowest scores in terms of the relative advantages of 4D BIM against these planning functions. Q25 was worded '*In general, the use of 4D BIM would be more effective in location based planning than our current practices'.* The comparatively low score that 4D BIM received here is surprising, because the visual benefits that the innovation offers seem ideally suited to the requirements of this planning function. Only 73.2% (n = 71) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.80 and the median response being 4.00 out of 5.00.

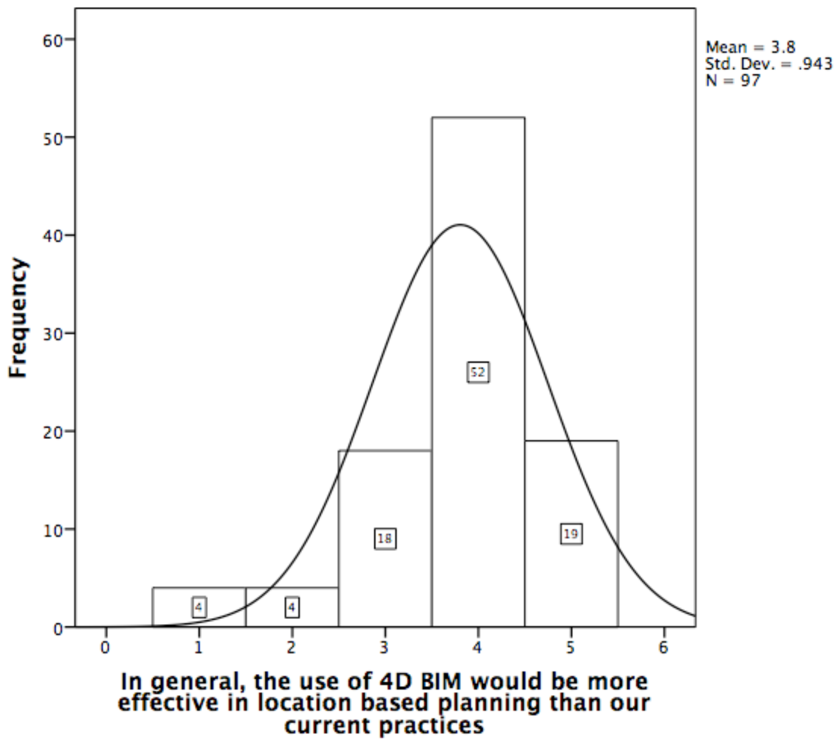

Figure 7.20: Relative advantage of location-based planning using 4D BIM innovation

Q26 was worded '*In general, the use of 4D BIM would be more effective for progress reporting than our current practices'.* 65.9% (n = 64) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.80 and the median response being 4.00 out of 5.00.

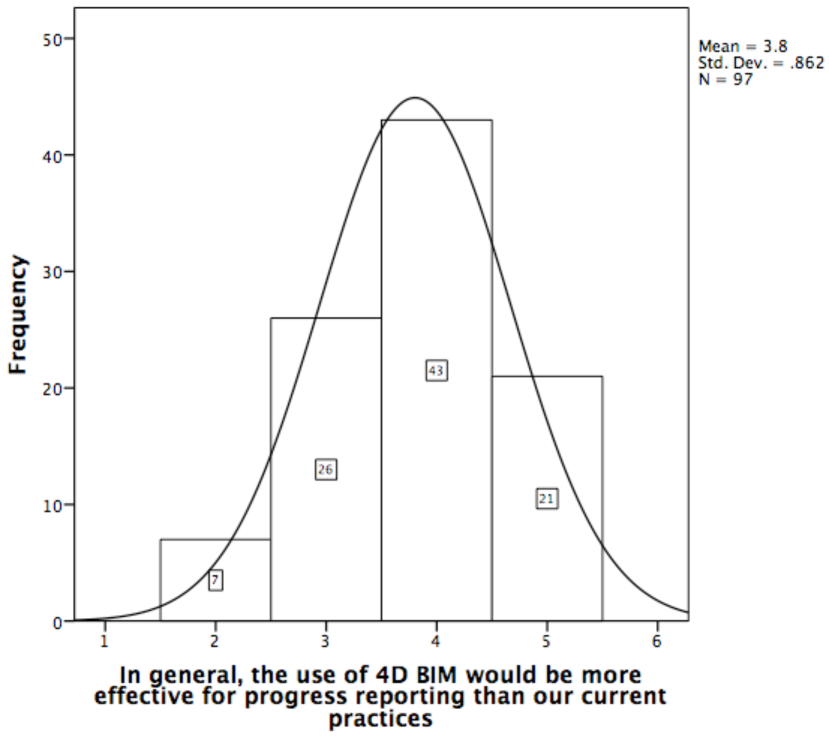

Figure 7.21: Relative advantage of progress reporting using 4D BIM innovation

Q27 was worded '*In general, the use of 4D BIM would be more effective for site layout planning (positions) than our current practices'.* 82.5% (n = 80) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 4.10 and the median response being 4.00 out of 5.00.

Q28 was worded '*In general, the use of 4D BIM would be more effective for logistics planning (movements) than our current practices'.* 84.5% (n = 82) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 4.13 and the median response being 4.00 out of 5.00.

Q29 was worded '*In general, the use of 4D BIM would be more effective for communicating working space than our current practices'.* 83.5% (n = 81) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 4.11 and the median response being 4.00 out of 5.00.

Q30 was worded '*In general, the use of 4D BIM would be more effective in safety planning than our current practices'.* 72.1% (n = 70) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.85 and the median response being 4.00 out of 5.00.

In order to rank, by function, the relative advantage offered by the use of 4D BIM over traditional methods a Relative Importance Index (RII) was calculated for each. The use of RII to illustrate the ranking of responses is relatively commonplace in construction management literature (see for example, Gündüz *et al.,* 2012, in the context of factors causing project delays). The RII was calculated as shown in the following Equation

$$RII = \frac{\sum W}{A \times N}$$

Where:

W is the weight given to each factor by respondents (from 1 to 5)

A is the highest weight (i.e. always 5) and

N is the number of responses

Table 7.2: Perceived Relative Importance (RII) and ranking of use of 4D BIM in 12 identified planning functions

Functions	N	∑ W	A x N	RII	Rank
Visualising the construction process	97	424	485	0.874	1
Facilitating understanding of the construction process	97	414	485	0.854	2
Logistics planning (movements)	97	401	485	0.827	3
Communicating working space	97	399	485	0.823	4
Site layout planning (positions)	97	398	485	0.821	5
Design interrogation	97	396	485	0.816	6
Planning construction methods	97	394	485	0.812	7
Work winning	97	379	485	0.781	8
Validating the time schedule	97	378	485	0.779	9
Safety planning	97	373	485	0.769	10
Location based planning	97	369	485	0.761	11=
Progress reporting	97	369	485	0.761	11=

It is clear from Table 7.2 that most of the highest ranked advantages of 4D BIM, as compared with current traditional approaches (visualising the construction process, facilitating understanding of the construction process, communicating working space) relate to its potential to alleviate the problems of communication and understanding that were identified earlier. Functions that represented the 'internal workings' of the planning process (validating the time schedule, location based planning, progress reporting) were the lowest ranked.

7.9.2 Assessing the relative advantages of 4D BIM against the construction planning process

The same method of analysis was used to assess the relative advantages of 4D BIM against the elements of the construction planning process which were identified previously in the literature as: (A) 'gathering information'; (B) 'identifying activities'; (C) 'assessing activity durations'; (D) 'planning the logical dependencies'; (E) 'planning the construction sequence'; (F) 'communicating the construction plan'; and (G) 'communicating project timescales'. Questions comparing traditional planning and 4D planning against each stage of the planning process had already been asked within the exploratory questionnaire stage, to determine if: 'traditional means were better than 4D'; whether 'traditional and 4D means were equal'; whether '4D offered a small improvement', or whether '4D offered significant improvement'. In this prior research, it was found that aside from the three categories in which 4D methods were clearly seen to offer significant improvements, where in: 'communicating the plan', 'gathering information' and 'sequence'. In the remaining categories, new methods were seen to offer only small improvements against traditional planning processes, and two areas where respondents felt that new methods did not seem to offer significant improvements were in 'assessing durations' and 'communicating project timescales'. All questions within this section sought to revisit this earlier research by assessing perceptions of the degree of relative advantage that 4D BIM innovation could provide against all stages of the construction planning process. Again because of the large number of questions, and because of the similarity of the charts used to visually communicate the results only data with the single highest and lowest scoring relative advantages in this section are illustrated graphically.

Q31 was worded '*In general, the use of 4D BIM would be more effective for gathering information than our current practices*' and 53.6% (n = 52) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.53 and the median response being 4.00 out of 5.00.

Q32 was worded '*In general, the use of 4D BIM would be more effective for identifying activities than our current practices*' and 69.1% (n = 67) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.75 and the median response being 4.00 out of 5.00.

Q32 was worded '*In general, the use of 4D BIM would be more effective for identifying activities than our current practices*' and 69.1% (n = 67) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.75 and the median response being 4.00 out of 5.00.

Q33 was worded *'In general, the use of 4D BIM would be more effective for assessing activity durations than our current practices'* however only 49.5% (n = 49) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.45 and the median response being 3.00 out of 5.00.

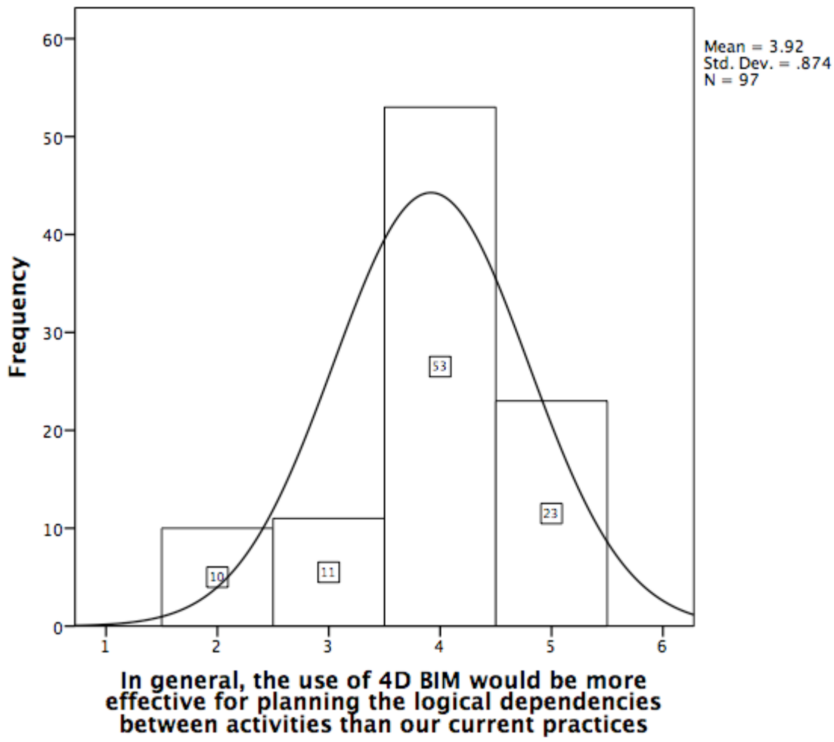

Figure 7.22: Relative advantage of planning logical dependencies using 4D BIM innovation

Q34 was worded '*In general, the use of 4D BIM would be more effective for planning the logical dependencies between activities than our current practices*' and 78.3% (n = 76) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.92 and the median response being 4.00 out of 5.00.

Q35 was worded '*In general, the use of 4D BIM would be more effective for planning the construction sequence than our current practices*' and 75.3% (n = 73) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.99 and the median response being 4.00 out of 5.00.

Q36 was worded '*In general, the use of 4D BIM would be more effective for communicating the construction plan than our current practices*' and 92.8% (n = 90) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 4.31 and the median response being 4.00 out of 5.00.

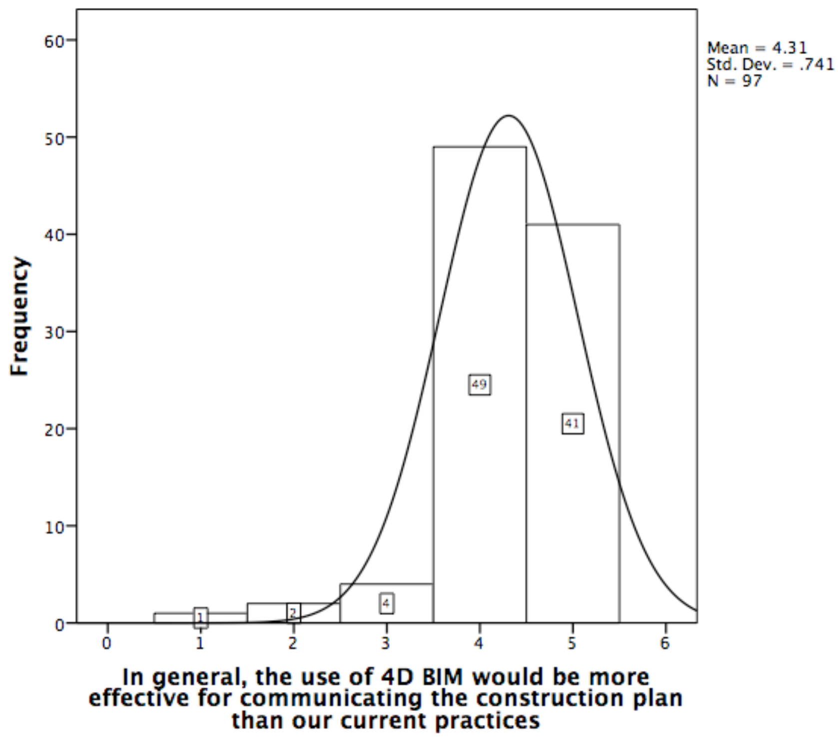

Figure 7.23: Relative advantage of communicating construction plan using 4D BIM innovation

Q37 was worded '*In general, the use of 4D BIM would be more effective for communicating project timescales than our current practices*' and 71.1% (n = 69) of the participants agreed that 4D BIM would be more effective in this function with the mean response being 3.81 and the median response being 4.00 out of 5.00.

Again, the RII, calculated as above, measures the relative importance of the use of 4D BIM in each of the above construction planning processes, as shown in Table 7.3

Table 7.3: Perceived Relative Importance (RII) and ranking of use of 4D BIM in 7 identified planning processes

Processes	N	∑ W	A x N	RII	Rank
Communicating the construction plan	97	418	485	0.862	1
Planning the construction sequence	97	387	485	0.798	2
Planning the logical dependencies	97	380	485	0.784	3
Communicating project timescales	97	370	485	0.763	4
Identifying activities	97	364	485	0.751	5
Gathering information	97	342	485	0.705	6
Assessing activity durations	97	335	485	0.691	7

The processes listed in Table 7.3 relate to what is described above as ‘internal workings’ of the planning process, i.e. ‘the things that planners do’. Again, the highest ranked item, by a considerable margin. related to the planner’s task of ‘communicating the construction plan’.

7.9.3 Assessing compatibility, complexity, trialability and observability

The remaining questions concerning the perceived attributes of 4D BIM innovation focussing on aspects of ‘compatibility’, ‘complexity’, ‘trialability’ and ‘observability’ as these have been identified as key independent diffusion variables in attempting to determine the rate of adoption of an innovation. Again 5-point Likert scale questions were used and the response options were consistent with those previously outlined.

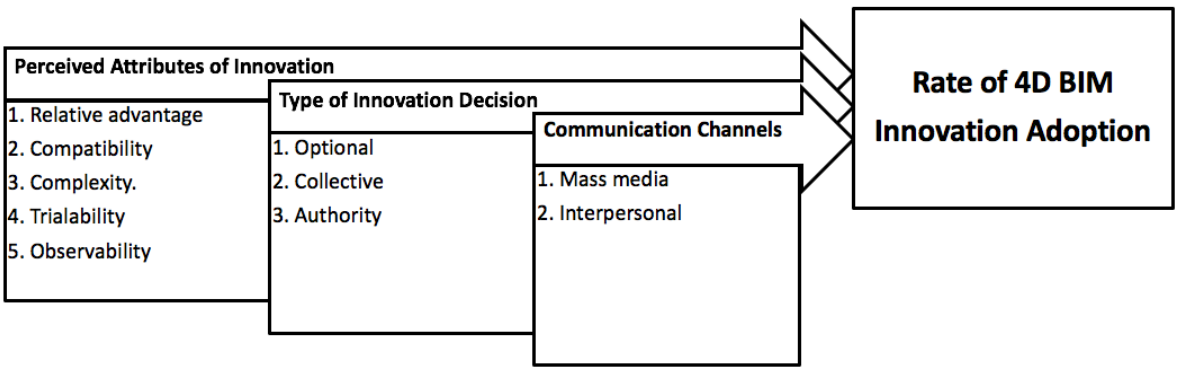

Figure 7.24: Variables determining the rate of 4D BIM innovation adoption. For reference only, identical to Figure 6.2

To assess 'compatibility', Q38 was worded *'The use of 4D BIM is compatible with our current practice of construction planning'.* Diffusion theory states that innovations that are compatible with existing infrastructures will diffuse more rapidly than those innovations that are not compatible with such infrastructures. 61.9% (n = 60) of the participants agreed with this statement with the mean response being 3.58 and the median response being 4.00 out of 5.00.

To assess 'complexity' three measures were used and these questions were the first of a series of negatively worded questions on the perceived attributes of 4D BIM. The first was Q39 which was worded *'4D BIM methods would be difficult to learn'* and only 23.7% (n = 23) of the participants agreed with this statement with the mean response being 2.84 and the median response being 3.00 out of 5.00. The second measure of complexity was tested in Q40 which was worded '*4D BIM methods would be difficult for planners to understand*' and again there was a low rate of agreement with this statement with only 14.4% (n = 14) of the participants agreeing. The mean response was 2.47 and the median response was 2.00 out of 5.00. The final measure of complexity was Q41 which was worded '*The training required in order to learn 4D BIM methods would be complicated'* and again there was a low rate of agreement with this statement with only 30.9% (n = 30) of the participants agreeing. The mean response was 2.86 and the median response was 3.00 out of 5.00. As diffusion theory considers that ease of comprehension by potential adopters' aids adoption rate, these lower scores can be considered to be positive results in terms of the potential adoption rate of 4D BIM innovation.

The final negatively worded question on the perceived attributes of 4D BIM was formulated to assess 'trialability'. Q42 was worded *'4D BIM methods would have to be experimented with before using to plan real construction work'.* Diffusion theory states that innovations that cannot be trialled without commitment are not readily adopted. 58.7% (n = 57) of the participants agreed with this statement with the mean response being 3.46 and the median response being 4.00 out of 5.00.

The final question concerning the perceived attributes of 4D BIM innovation related to 'observability'. Diffusion theory states that innovations that are more visible or have more visible positive results are adopted more readily. Q42 was worded '*It is easy to see the impact that 4D BIM has on construction planning effectiveness'* and 74.2% (n = 72) of the participants agreed with this statement with the mean response being 3.80 and the median response being 4.00 out of 5.00.

Attention now turns to the next in the series of independent diffusion variables that further help explain the rate of adoption of 4D BIM - the types of innovation decisions made, and the communication channel preferences for obtaining information about 4D BIM and influencing decisions about 4D BIM adoption or rejection decisions.

7.10 Decision types and communication preferences

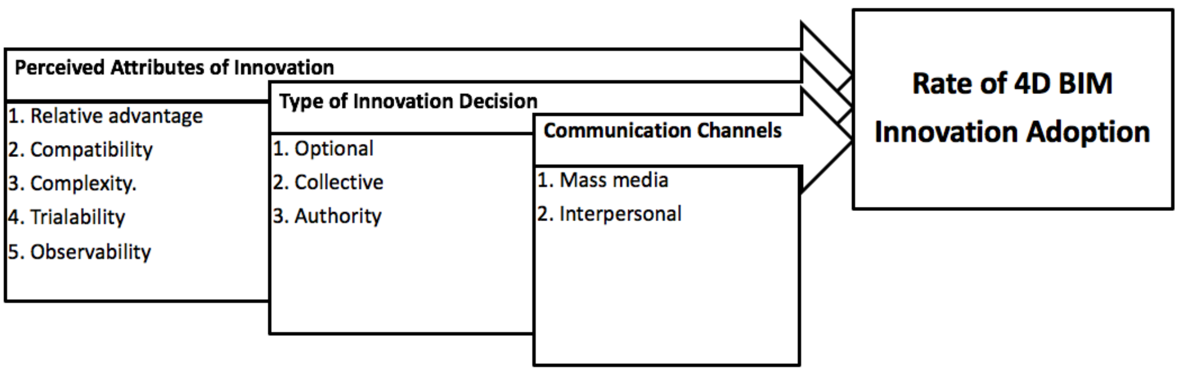

Figure 7.25: Variables determining the rate of 4D BIM innovation adoption. For reference, identical to Figure 6.2

This section looks at the remaining independent diffusion variables that further help explain the rate of adoption of 4D BIM. The questionnaire asked a series of categorical type questions, which explored the types of innovation adoption/rejection decisions being made, as well as the communication channel preferences for obtaining information, then influencing adopt/reject decisions about 4D BIM.

Before exploring decision types, it was first useful to determine if any definite 'adopt' or 'reject' decision had been made regarding 4D BIM. Q44 asked '*Please confirm if a decision has been made to adopt or reject the use of 4D BIM for the planning of construction work*'. Three response options were offered: 'adopt', 'reject' and 'undecided/no decision made'. 67% (n = 65) confirmed that an adopt decision had been made, 1% (n = 1) confirmed that a reject decision had been made, and the remaining 32% (n = 31) confirmed that they were undecided and that no decision had been made. Depending upon their response, the questionnaire was designed to automatically filter 'adopt' responders to Q45, and the 'reject' responders to Q46. The 31 who selected the 'undecided/no decision made' response option were not asked any other questions about decision types, and instead directed automatically to the first question about communication channels (Q47).

Q45 asked the respondent: '*If possible, please explain which type of decision was made to adopt 4D BIM*'*.* The following instructions helped provide detail about the three available response options: '*A decision to adoption 4D BIM innovation could have been made as a separate, or as a joint decision: an 'Optional Decision', is one that is made by the individual (i.e. you); a 'Collective Decision' is one that is made by consensus and 'Authority Decision', is one that is made by organisational upper management".* From the 65 respondents who confirmed that an adopt decision had been made, the most frequent type of decision was an ‘authority decision’ with 46.2% (n = 30) of the respondents selecting this option. The next most frequent was ‘collective decision’ with 33.8% (n = 22) and the least frequent option was ‘optional decision’ with 20% (n = 13) of respondents selecting this option (*note ‘valid percentages’ were used for this question so that the responses from the 65 respondents totalled 100.0%*). Q46 asked, ‘*If possible, please explain which type of decision was made to reject 4D BIM*’, and the sole respondent who advised that a definite reject decision had been made, confirmed that this had been a ‘collective decision’.

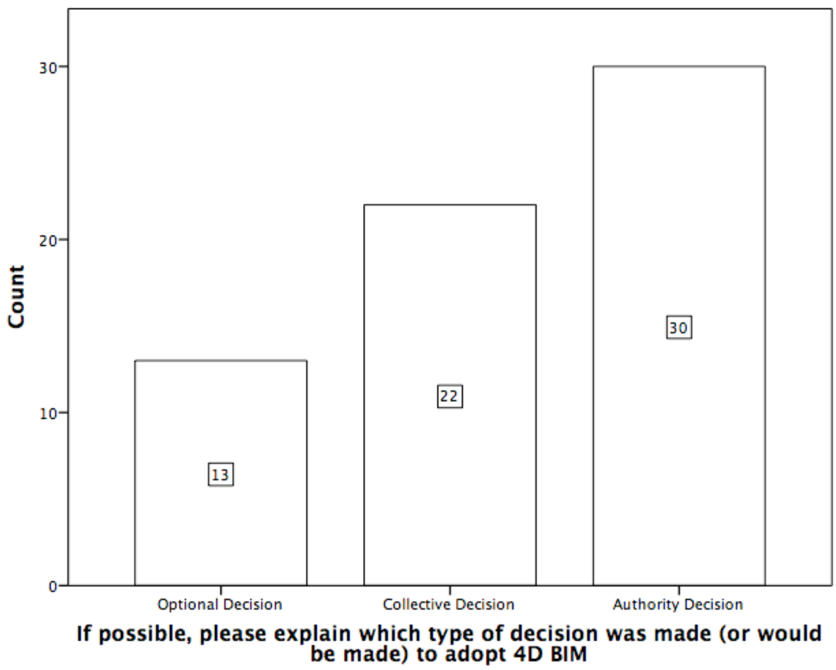

Figure 7.26: Decision classifications of adopters of 4D BIM innovation

From the data gathered it was possible to perform bivariate analysis to test for associations between various organisational characteristics and the types of organisational innovation adoption decisions made, to see if certain types of organisations are likely to make certain kinds of decisions. Characteristics of company age (by decade) and reported organisational BIM maturity were both tested, however in these tests, no significant associations were found. However, when analysing the 65 cases where a definite company 'adopt' decision had been made, it was possible to test for associations between the size of the company, and the types of organisational decisions that were made:

H_0: There is no relationship between company size compared with innovation adoption decision types.
H_A: There is a relationship between company size compared with innovation adoption decision types.

Using a Fishers Exact test gave a statistic of .019, meaning that H_0 could be rejected in favour of H_A, that: *There **is** a relationship between company size compared with innovation adoption decision types.* Interrogation of the data produced in the cross-tabulation about this relationship suggests that larger companies (250 persons+) are much more likely to require 'authority-decisions' to be made. This would go some way to confirming that within larger companies it is more usual that multiple persons are involved in innovation adoption-rejection decisions. Adoptions are likely to be related to strategic decisions, and direction is required before an individual working for a larger organisation can subsequently adopted the innovation. This contrasts with smaller enterprises, where there appears to be more flexibility.

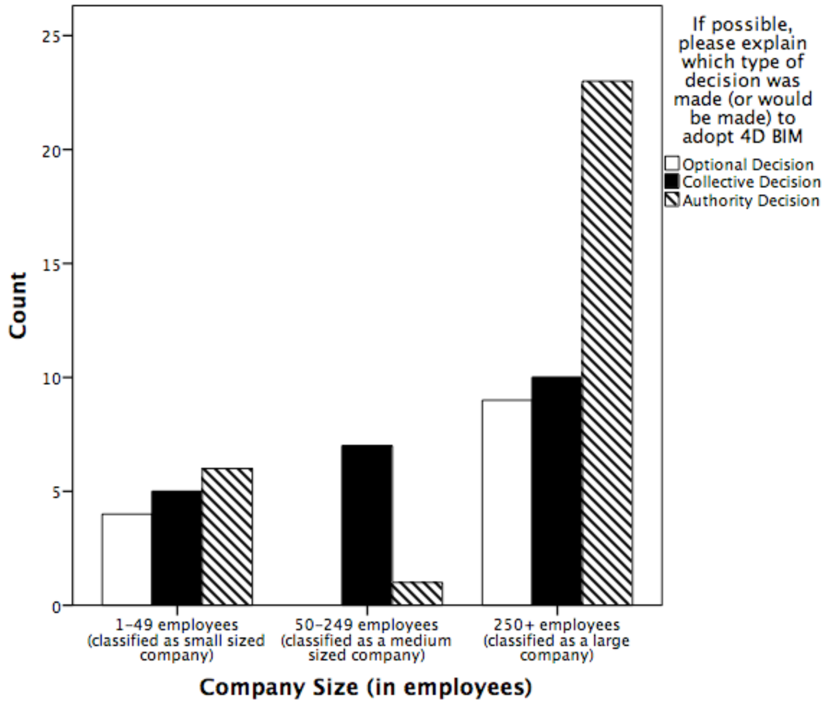

Figure 7.27: Types organisational innovation adoption decisions made against company size

The final two questions were concerned with exploring communication channel preferences of the respondent[6]. The reader is reminded that IDT states that 'innovators' and 'early adopters' favour 'external communication channels' for obtaining information whereas 'internal communication channels' particularly between 'near-peers', are more favoured by 'late adopters' and 'laggards'.

Q47 asked the respondents to select their preferences between external sources (*advised as sources such as mass media including websites, journals, magazines and government*) and internal sources (*advised as colleagues, peers, workmates or interpersonal networks*) for the obtaining of information about 4D BIM which is important at the 'knowledge' stage of the innovation-decision process. 53.6% (n = 52) of respondents identified external sources as being their preference for the obtaining of information about 4D BIM innovation, with the

6 Further questions over communication channel preferences were also included in the concurrent semi structured interviews.

remaining 46.4% (n = 45) of respondents identifying internal sources as being their preference.

Q48 asked the respondents to select if such external sources or internal sources would have the biggest impact on their own personal decision in relation to their adoption or rejection of 4D BIM (the ‘persuasion stage’ of the innovation-decision process). This time 64.9% (n = 63) of respondents identified that ‘internal sources’ would have the biggest impact on their own personal decision in relation to their adoption or rejection, with the remaining 35.1% (n = 34) of respondents identifying ‘external sources’ would have the greater influence.

Although these results comply with aspects of IDT no statistical significance was found in test of association between communication channel preferences and adoption levels of 4D BIM innovation.

7.11 Which variables determine the rate of 4D BIM innovation adoption?

Research Objective 4.4: ‘explore and explain the rate of adoption of 4D BIM innovation’, was partially satisfied by the result of a statistical test ‘exploring’ the usual time lag (rate) recorded between awareness and adoption which was found to be between 2.38–3.00 years (28.5–36.0 months). To further help ‘explain’ the rate of adoption the predictors identified by Rogers (2003) as independent variables that are likely to determine this rate (illustrated in the figure below) must be returned to. Each of these independent variables can be tested against the adoption of 4D BIM innovation, which was measured by way of a simple categorical YES/NO variable in Q14 for ’*Do you currently use 4D BIM in your* *construction planning practices?'* where 51.5% (n = 50) of the total respondents confirmed use.

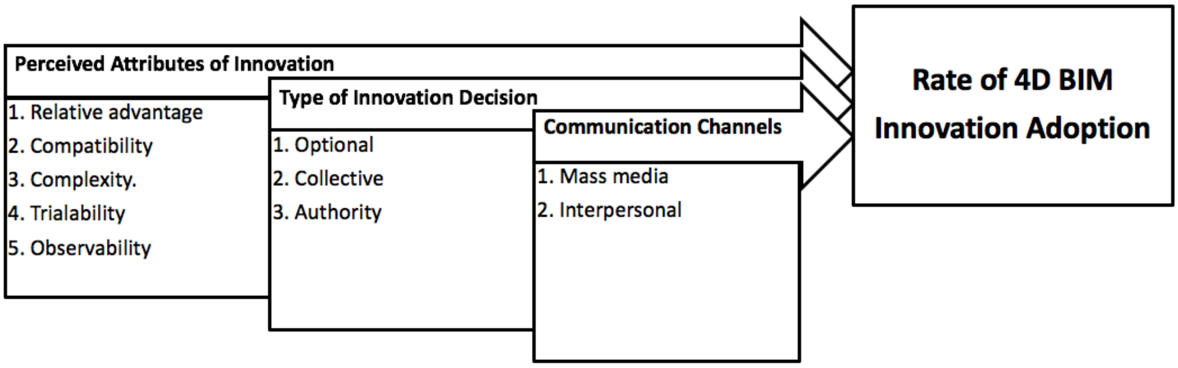

Figure 7.28: Variables determining the rate of 4D BIM innovation adoption. Adapted from Rogers (2003). For reference, identical to Figure 6.2

As discussed previously, ordinal variables were used for the '*perceived attribute*' questions and categorical variables were used for the '*decision type*' and '*communication channels*' questions meaning that Chi-square or Fishers Exact tests could be used to test for these associations:

- Relative advantages of 4D BIM *against* use of 4D BIM.
- Compatibility of 4D BIM *against* use of 4D BIM.
- Complexity of 4D BIM *against* use of 4D BIM.
- Trialability of 4D BIM *against* use of 4D BIM.
- Observability of 4D BIM *against* use of 4D BIM.
- Types of innovation adoption decisions taken *against* use of 4D BIM.
- Communication channel preferences *against* use of 4D BIM.

This required 28 separate tests to be performed. In each test, appropriate null (H_0) and alternative (H_A) hypotheses were formulated. Significant associations were only found in the tests of association involving 'compatibility' and 'trialability' as a means of explaining the rate of 4D BIM innovation adoption and the tests used to determine these findings are detailed further below. As no significant associations were found in many of these tests, only concise summary details are provided for the results of these tests as follows:

- Across 12 identified ‘relative advantages’ of 4D BIM ‘construction planning functions’, no significant associations were found when these independent variables were tested for association against the dependent variable.
- Across the 7 identified ‘relative advantages’ of 4D BIM in each stage of the ‘construction planning process’ no significant associations were found when these independent variables were tested for association against the dependent variable. Although a Fishers Exact Test showed a statistic of .079 for the relative advantage of using 4D BIM for communicating the construction plan which is slightly outside the margins of significance.
- Across the three measures of the ‘complexity’ against use of 4D BIM innovation no significant associations were found when these independent variables were tested for association against the dependent variable.
- In the measure of the ‘observability’ of the visible positive results of 4D BIM against the use of 4D BIM innovation no significant associations were found when this independent variable was tested for association against the dependent variable.
- Despite the categories of ‘innovation decisions types’ being described by Rogers (2003) as an independent (predictor) variable that would affect the dependent variable - the adoption of 4D BIM, no significant associations were found when these variables were tested for association.
- Also, despite the ‘communication channel preferences’ being described by Rogers (2003) as independent (predictor) variables that would affect

the dependent variable - the adoption of 4D BIM, no significant associations were found when these variables were tested for association.

7.11.1 Key tests of statistical association in determining the rate of 4D BIM innovation adoption

To test the 'compatibility' against use of 4D BIM, competing null (H_0) and alternative (H_A) hypotheses were formulated:

H_0: There is no relationship between how compatible 4D BIM is with the current practice of construction planning compared *against* the personal adoption and use of 4D BIM.

H_A: There is a relationship between how compatible 4D BIM is with the current practice of construction planning compared *against* the personal adoption and use of 4D BIM.

Crosstab

			Do you currently use 4D BIM in your construction planning practices?		
			Yes	No	Total
Compatibility: The use of 4D BIM is compatible with our current practice of construction planning	Strongly disagree	Count	0	3	3
		% of Total	0.0%	3.1%	3.1%
	Disagree	Count	5	8	13
		% of Total	5.2%	8.2%	13.4%
	Neutral	Count	13	8	21
		% of Total	13.4%	8.2%	21.6%
	Agree	Count	20	25	45
		% of Total	20.6%	25.8%	46.4%
	Strongly agree	Count	12	3	15
		% of Total	12.4%	3.1%	15.5%
Total		Count	50	47	97
		% of Total	51.5%	48.5%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	10.756[a]	4	.029	.023		
Likelihood Ratio	12.306	4	.015	.019		
Fisher's Exact Test	10.320			.026		
Linear-by-Linear Association	4.167[b]	1	.041	.044	.026	.010
N of Valid Cases	97					

a. 2 cells (20.0%) have expected count less than 5. The minimum expected count is 1.45.

b. The standardized statistic is -2.041.

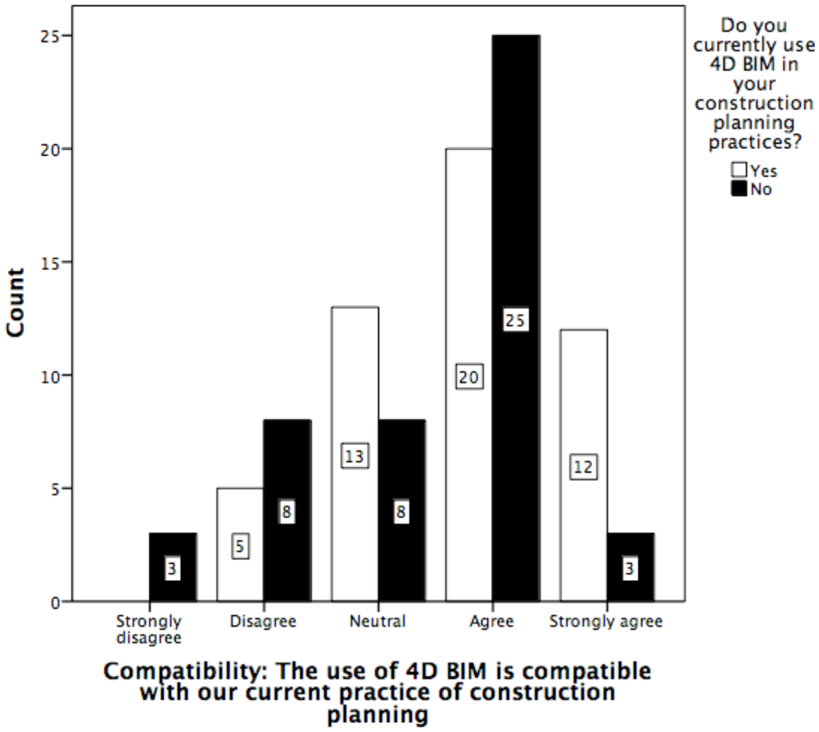

Figure 7.29: Tests of association: Compatibility against personal use of 4D BIM innovation

In this test, all 97 cases could be used. A Fisher's Exact Test gave the statistic of .026 which meant that H_0 could be rejected in favour of H_A: *There is a relationship between how compatible 4D BIM is with the current practice of construction planning compared against the personal adoption and use of 4D BIM Innovation.* Further exploration of the data produced in the cross-tabulation appears to suggest that whilst both adopters and non-adopters alike consider 4D BIM to be compatible with current planning practices, those who have adopted

4D BIM are far less likely to consider 4D BIM incompatible with current planning practices.

The second test concerns the ‘trialability’, against use of 4D BIM innovation. Competing null (H_0) and alternative (H_A) hypotheses were formulated as follows:

H_0: There is no relationship between a need to experiment with 4D BIM prior to using it to plan real construction work, compared *against* the personal adoption and use of 4D BIM.

H_A: There is a relationship between a need to experiment with 4D BIM prior to using it to plan real construction work, compared *against* the personal adoption and use of 4D BIM.

Crosstab

			Do you currently use 4D BIM in your construction planning practices?		
			Yes	No	Total
Trialability: 4D BIM methods would have to be experimented with before using to plan real construction work	Strongly disagree	Count	4	0	4
		% of Total	4.1%	0.0%	4.1%
	Disagree	Count	15	3	18
		% of Total	15.5%	3.1%	18.6%
	Neutral	Count	8	10	18
		% of Total	8.2%	10.3%	18.6%
	Agree	Count	17	26	43
		% of Total	17.5%	26.8%	44.3%
	Strongly agree	Count	6	8	14
		% of Total	6.2%	8.2%	14.4%
Total		Count	50	47	97
		% of Total	51.5%	48.5%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	14.313[a]	4	.006	.004		
Likelihood Ratio	16.593	4	.002	.003		
Fisher's Exact Test	14.223			.005		
Linear-by-Linear Association	10.450[b]	1	.001	.001	.001	.000
N of Valid Cases	97					

a. 2 cells (20.0%) have expected count less than 5. The minimum expected count is 1.94.

b. The standardized statistic is 3.233.

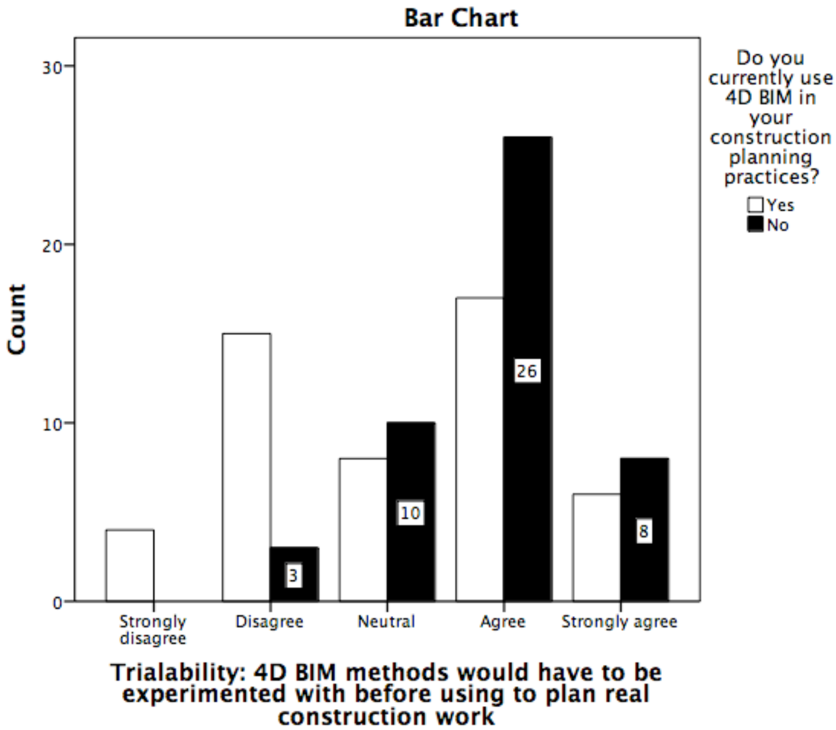

Figure 7.30: Tests of association: Trialability against personal use of 4D BIM innovation

In this test, all 97 cases could be used. A Fisher's Exact Test gave the statistic of .005 which meant that H_0 could be rejected in favour of H_A: *There is a relationship between a need to experiment with 4D BIM prior to using it to plan real construction work, compared against personal adoption and use of 4D BIM Innovation.* Further exploration of the data produced in the cross-tabulation appears to suggest that whilst adopters are equally likely to agree or disagree with the need for experimenting or trialling 4D BIM (i.e. there is no real trend in this category), persons who have not yet adopted, much more strongly consider there to be a need to trial 4D BIM innovation before using it to plan real construction work.

7.12 Summary of Explanatory Questionnaire

The explanatory survey looked to investigate the diffusion of 4D BIM within UK construction planning practice and used several of the key variables from classic IDT as well as constructs gained from the literature review in the design of the survey questions. Data yielded from the results of the questionnaire was analysed using descriptive and inferential statistics and the full list of all summary results from the inferential analysis undertaken in this research is reproduced in the conclusions chapter. Results that can partially satisfy research objectives 4.3: '*Explore the innovativeness of members of the construction social system'*, show that organisational characteristics were considered to be more important than individual user characteristics in determining user innovativeness. Results that were able to partially satisfy research objectives 4.4: ''*Explore and explain the rate of adoption of 4D BIM innovation''* included tests of correlation proving how first adoption of 4D BIM innovation is related to timing of first awareness of the innovation, and tests of association related to concepts of 'compatibility' and 'trialability', and to a lesser non-statistically significant degree, the relative advantage of the use of 4D BIM for communicating the construction plan. Interpreting these findings show that:

- There is a strong positive relationship between the timing of first awareness and the timing of first adoption of 4D BIM innovation ($r = .764$). The usual time lag recorded between awareness and adoption can be confirmed as being between 2.38–3.00 years (28.5–36.0 months), and that;
- In order for 4D BIM innovation to diffuse more rapidly potential adopters have to be convinced that whilst 4D BIM is a technological process based innovation, it is also a modular innovation (Slaughter 1998; 2002) which may produce significant improvements but does not may not require alteration of other system level components and therefore is compatible

with existing planning practices; that the innovation can be trialled in a safe environment prior to use on a live construction project; and that the relative advantage of being able to communicate the construction plan using 4D methods rather than traditional formats mean that this innovation is worth adopting.

These themes will be further explored in the Chapters 8 and 9 which provide analysis from the qualitative semi-structured interviews. In terms of credibility of this phase of explanatory research, the research can be replicated, and as the measures used for the concepts are stable it is entirely repeatable, although again as with the previous exploratory survey undertaken and written up in Chapter 5, because of the impact of the government BIM Mandate; the likely changes to future project requirements and the process improvement BIM journeys that organisations and individuals will go through it is quite likely that different responses would be received should the survey ever be ran again. The study was designed to make use of classic innovation diffusion variables which helps to address any concerns of internal validity. While it is inappropriate to assert that the results are generalizable to all members of the wider construction population because of the nature of purposive sampling, future readers considering the potential diffusion of a modular technological process based innovation process may well benefit from consideration of these results, and the methods of statistical analysis employed. They may also find value in the following results from the semi-structured interviews that are now provided in Chapters 8 and 9.

Chapter Endnotes

[i] VIRCON - The Virtual Construction Site: This research focused on a ‘decision support system for construction planning’. It was a collaborative project that used a virtual replication of an actual construction project that been delivered for a University. A project database was developed consisting of building components, integrated with the AutoCAD 2000 design package, MS Project scheduling software and Graphical User Interfaces (GUI), making use of the then new Uniclass standard classification method to integrate Product Based Structure and Work Breakdown Structure systems. The aim of the VIRCON project was to develop tools to assist in the intelligent construction planning process, and the first two streams of development were focussed on aspects of 4D planning and Critical Space Analysis (CSA).

Chapter 8: Explanatory Semi-Structured Interviews – Part 1

The questionnaire detailed in the previous chapter concluded by asking participants if they would be willing to participate in a follow up interview. 13 participants agreed and telephone interviews were held between May - July 2015. Because of the volume of relevant qualitative data generated, the results of these interviews are spread across Chapters 8 and 9. As detailed in Chapter 6, question design was informed by constructs from across the literature as well as IDT variables. As such, Chapter 8 reveals broad insights around innovation in construction, whereas Chapter 9 is focused, mainly on the IDT variables. Whilst sub-objectives (4.3) 'explore and explain the innovativeness of members of the construction social system', and (4.4) 'explore and explain the rate of adoption of 4D BIM innovation' were partially through results presented in Chapter 7, these next chapters further address these sub-objectives and provides further explanation, as well as addressing (4.5) 'explore and explain the consequences of 4D BIM innovation'. A subsequent chapter (10) then addresses **Research Objective 5** by, through this study of 4D BIM, developing a model that further informs innovation diffusion theory.

8.1 Interview preparation and process

The question list was sent in advance to allow participants to more fully consider their responses in advance of the interview. **Appendix D-4** presents the research instrument used. Again, **Appendix E-4** identifies the links between the question themes and the relevant literature for all key variables in this research instrument. The audio from all interviews was first captured digitally and then verbatim transcripts were produced using a word processing application. As previously, all participants agreed to take part and completed the necessary research participant consent forms (RPCF) to satisfy the research ethics policy requirements of the awarding institution. NVivo was again used as the Computer Assisted Qualitative Data Analysis Software (CAQDAS) package to aid the analysis of the qualitative data. Codes were pre-assigned to capture and compare the responses against each question with subsequent coding occurring during the analysis as themes emerged.

Name	Sources	Referen...	Created On	Created By
BIM	12	36	3 Aug 2015, 22:16	BJG
Impact on planning	12	24	3 Aug 2015, 22:16	BJG
Production Information	11	12	3 Aug 2015, 22:16	BJG
Commitment	2	2	13 Aug 2015, 15:08	BJG
Communication Channels	11	14	3 Aug 2015, 22:20	BJG
External communication channels	5	5	3 Aug 2015, 22:20	BJG
Internal communication channels	7	7	3 Aug 2015, 22:21	BJG
Consequences	0	0	3 Aug 2015, 22:22	BJG
Anticipated consequences	8	9	3 Aug 2015, 22:23	BJG
Desirable consequences	9	12	3 Aug 2015, 22:22	BJG
Direct consequences	6	6	3 Aug 2015, 22:23	BJG
Indirect consequences	6	7	3 Aug 2015, 22:23	BJG
Unanticipated consequences	5	6	3 Aug 2015, 22:23	BJG
Undesirable consequences	10	13	3 Aug 2015, 22:23	BJG
Innovation	12	42	3 Aug 2015, 22:11	BJG
Industry Structure	10	12	3 Aug 2015, 22:14	BJG
Innovation implementation	12	16	3 Aug 2015, 22:14	BJG
Innovation in construction	11	13	3 Aug 2015, 22:13	BJG
Innovation-decision process	0	0	3 Aug 2015, 22:17	BJG
Confirmation	9	9	3 Aug 2015, 22:20	BJG
Decision	10	11	3 Aug 2015, 22:19	BJG
Implementation	11	14	3 Aug 2015, 22:19	BJG
Initial Knowledge	12	13	3 Aug 2015, 22:17	BJG
Observability	5	5	15 Aug 2015, 14:29	BJG
Persuasion	11	11	3 Aug 2015, 22:17	BJG
Postponed adoption	2	3	10 Aug 2015, 13:02	BJG
Key Actors	11	24	3 Aug 2015, 22:21	BJG
Change Agent(s)	10	10	3 Aug 2015, 22:21	BJG
Opinion Leader(s)	11	14	3 Aug 2015, 22:22	BJG
Perceived Characteristics	0	0	15 Aug 2015, 14:28	BJG
Compatibility	2	2	15 Aug 2015, 14:28	BJG
Complexity	1	1	15 Aug 2015, 14:29	BJG
Relative Advantage	4	6	15 Aug 2015, 14:28	BJG
Trialability	1	1	15 Aug 2015, 14:29	BJG
Time predictability	11	11	3 Aug 2015, 22:24	BJG

Table 8.1: 'Nodes' in Semi-Structured Interviews.

The question list provided to the interviewees (refer to Appendix D-4) included one artefact related to a series of questions around the innovation-decision process (detailed below) and the following explanatory instructions which were also read aloud at the commencement of each interview:

> *'An innovation is defined by Everett Rogers (2003) as "an idea, practice or object that is perceived as new by an individual or other unit of adoption". The first few questions (Q1-3) focus on innovations and the construction industry in general. Then the questions focus specifically on BIM (Q4-5) and 4D BIM innovations (Q-10). The last question relates to construction project time predictability'.*

Analysis is presented under the following headings in Chapter 8:

- Innovation in the construction industry.
- Innovation implementation.
- The impact of BIM.

And in Chapter 9 the analysis is structured around:

- The innovation-decision process.
- Communication channels.
- Key actors.
- Consequences of 4D BIM innovation.
- The time predictability problem.

Thereafter, Chapter 10 presents a new model of the innovation-decision process.

8.2 Innovation in construction

Many researchers (Slaughter, 1988; Koskela and Vrijhoef 2001; Gambatese and Hallowell, 2011; Demian and Walters, 2014) believe that the industry suffers from a low rate of innovation. The participants were asked:

> ***"What is your assessment of the level of innovation in the construction industry?"***

Construction was described as: *"Not a highly innovative industry"* (Participant 41), and there was general agreement with the literature that there was a low rate of direct innovation and that construction: "*lags behind other industries*" (Participant 195). Criticism of traditional construction methods and techniques were expressed, with concerns that even though newer, safer means of performing construction work were available, low levels of such technological innovation adoption were apparent. Participants considered that typical innovation adoption in construction related to alternative or substitution materials, such as *"the likes of light fittings* [that] *have changed to LED types*" (Participant 241). These are examples of what Slaughter (1998; 2000) called 'incremental innovations' which create improvements to existing practice with minimal impacts upon the wider system. Despite this, several participants were optimistic about recent trends in construction innovation: "*it is improving* [in] *the last few years"* (Participant 189) and future opportunities: "*there are lots of barriers in the way, but I do think it's getting there"* (Participant 203). Several barriers were identified that related to the structure of the industry.

8.3 Industry structure

Researchers such as Walker (2016) have argued that innovation must be considered within the context of the industry and several unique industry characteristics were addressed in the literature review - that it is analogous to a decentralised complex system, and that the project based nature of the industry and the use of Temporary Project Organisations (TPO) directly affect the impact of innovations (Dubois and Gadde, 2002; Winch, 2003; Taylor and Levitt. 2004a; 2004b; Harty, 2005; Emmitt, 2010). Participants were asked:

> ***"Does the way that the industry is structured affect the levels of construction innovation?"***

This question generated emphatic responses particularly around the location and project based nature of the industry: *"I certainly think that there's lot more challenges to it than the likes of the manufacturing industries, obviously* [the] *location of where you are building compared to being in a more static place … we are building in a different place each time …* [and] *… the structure, culturally is very different"* (Participant 203).

IDT considers 'the nature of the social system', its norms, and degree of network interconnectedness, to be a key aspect when considering innovation diffusion. Rather than explicitly discussing structure, participant concerns were focussed more on the norms of the construction system including aspects of fragmentation, procurement processes, the market environment and business practices whilst dimensions of 'culture', 'time' and 'system complexity' featured heavily across these aspects.

Fragmentation and increases in niche trade specialisms beside a decline in multi-skilled organisations and operatives were considered: "*it's very 'silo'd' … and that's the way construction is, you don't tend to find someone who can do everything*" (Participant 245). This latter point means that the industry heavily relies upon the use of multiple smaller contractors within TPOs, which contributes to the problems identified by Taylor and Levitt (2004a; 2004b) of diffusing systemic process based innovations such as 4D BIM, across multiple organisational boundaries, a point considered by one participant:

> *"The fragmented nature of industry is a big blocker to innovation adoption, e.g. with companies becoming BIM ready, the large construction companies, the designers, the clients are all pretty much getting ahead of the game. It's the supply chain who are struggling to keep up, and obviously, the way the industry is structured means that you rely on these SME's"* (Participant 15).

Procurement tender processes were discussed as both enabling and preventing innovation diffusion, and appears dependent upon project stakeholder attitudes:

> *"We have got some clients that want to encourage innovation in tenders and some are just not interested whatsoever, and what you put* back [tender return] *they want to be on the basis of what their design team has come up with, and don't want to consider anything else …. we have got design teams who are so precious about what they have come up with and aren't open to any other alternatives whatsoever"* (Participant 123).

… and available time:

> *"so many projects* [tendered for] *are under pressure to be turned around quickly, we're just not given the opportunity we don't have the time to explore other options …. and it just doesn't facilitate innovative thinking"* (Participant 123).

Although in contrast, within alternative procurement practices such as two-stage tender opportunities, participants did see the greater availability of time as useful in the promotion of innovations.

Another norm of the construction social system is the market environment requiring actors to operate and make lower profit in comparison with other sectors (Reichstein, Salter and Gann, 2005). Because of these more restrictive margins, along with high potential for failure, this is a system which does not adequately incentivise individual organisations to seek competitive advantage through self-innovation generation (Manley and Mcfallan 2006). Organisations can therefore be characterised as being risk adverse and unwilling to self-generate innovations nor engage with existing innovations because of the high degree of uncertainty associated with these innovations (Larsen 2005; Larsen and Ballal 2005), which in turn has a direct impact on the levels of construction wide innovation. This situation was considered by Participant 210, *"I suppose you could brand it as culture, but I think is more to do with the way we focus on lowest price wins … it goes back to our business practices and it is cost as a focus and the fact that we are always trying to pursue marginal gains"*.

In addition to industry structure, the culture and set up of organisations operating within such a complex system were considered. Issues discussed included aspects of business strategy and organisational hierarchy and learning such as the mechanisms for capturing and sharing knowledge about innovations. Participant 210 criticised the approach of construction organisations of following a *Red Ocean* strategy - attempting to out-performing competing organisations in winning work in over-crowded markets, rather than pursuing a *Blue Ocean* strategy (see Kim and Mauborgne, 2004) of product and service differentiation, achieved at lower costs using existing radical or disruptive innovations to offer customers greater value and therefore make competitors inconsequential. Construction was described as knowledge intensive and there was belief that company leaders, able to facilitate innovation, are typically more rigid in approach than younger staff pushing innovations: *"It seems an ageist thing that knowledge is usually gained through age but the problem is … that the older people don't tend to want to engage in new approaches, new technologies"* (Participant 246). This is reminiscent of the 'digital immigrants' and 'digital natives' argument (covered in C4.4), regarding technologically-adverse and technologically-accepting persons, often attributed to generational differences (Prensky, 2001a; 2001b; Eynon, 2011; 2014; Danker and Jones, 2014) which was observed by the researcher first-hand in the earlier case study. In terms of organisational learning one participant considered:

> *"Certainly speaking* [about my company]*, the way it's structured, I think innovation could be shared better, and if that is true, within the industry, then I think there is certainly a large step forward to be made. I'm sure there is lots of*

innovation that's been used in other parts of our business, which we don't know about" (Participant 189).

8.4 Innovation implementation

As found within the interviews undertaken within the earlier exploratory case study (Chapter 4) there are differing perspectives of the best means of implementing construction innovations. Participants were asked:

"How are industry innovations best implemented?"

Participants considered this question across a range of industry-, organisation-, and project-level perspectives. Dubois and Gadde, (2002, p629) argued that "*government regulations and industry standards make the system difficult to change, and this in turn hampers innovation*" however government incentives can promote innovation, although the difficulty of promoting change by policy makers was acknowledged by Whyte and Sexton (2011, p473) who highlighted this *"require*[s] *cooperation from numerous dispersed actors with divergent interests"*. Regarding implementation of BIM innovation at industry-level the current government strategy was considered (HM Government 2011; 2013) as a means of championing BIM, and Caerteling *et al*., (2013) found such behaviour prompts involvement by key decision makers, helps overcome regulatory impediments and has a greater impact than other means of governmental aid such as technical or financial means. The creation of the Government Construction Strategy which details the 2016 BIM Level 2 deadline was considered to be an appropriate means of encouraging innovation diffusion across the industry, as considered by one participant: "*if you look at it in macro level - top down, I would say it provides the focus, it provides an aim for people in terms of where to get to,* *you know, gamification of the project environment, gamification of the industry … the government strategy provides the aim"* (Participant 210).

At company- and project-levels, participants frequently considered the most effective direction of implementation, which relates back to the model of construction innovation processes developed by Winch (1998, p273) who argued that the two dimensions of top down adoption/implementation and bottom-up problem solving/learning approaches are equally as important in the construction innovation process. Whereas more recent literature considers that construction innovations can only be successfully implemented if driven by lower project level staff (Arayici *et al*., 2011; Davies and Harty, 2013a).

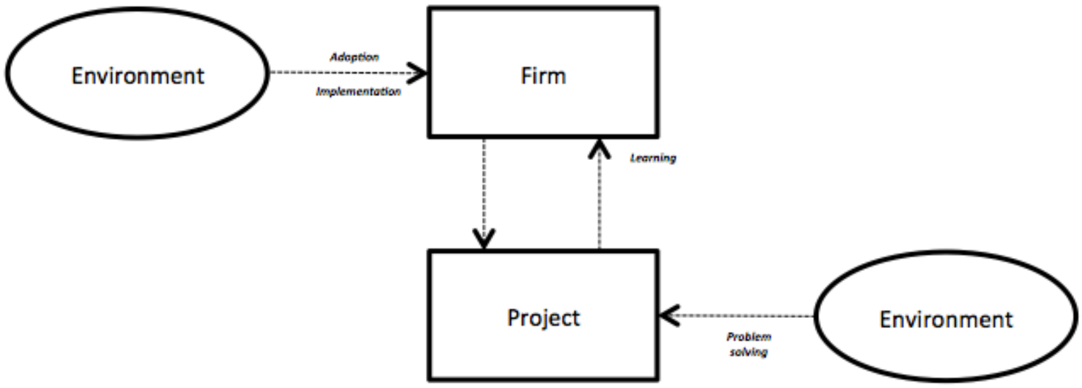

Figure 8.1: Construction innovation processes. Reproduced from Winch (1998). For reference, identical to Figure 4.4

Those who argued that innovations within organisations should be implemented from the top down considered aspects such as company strategy, vision and policy set by company principals and the accountability that these actors hold: *"I don't think it has to be fully reliant on the guys from the top, but they do have to have definitely an appreciation of the level of responsibility."* (Participant 203).

Several larger interview excerpts now are provided in their entirety including exchanges between Interviewee [I] and Researcher [R] to highlight the strength of feeling from these participants that innovation is best implemented within organisations from the top down direction. The first excerpt also refers to a company vision reminiscent of the ‘blue ocean’ strategy discussed above:

Excerpt from interview with Participant 193:

> [I] *[My company] are very driven by this concept of a unique business opportunity. They want to offer something different to the client that is something that is significantly better than its competitors. That mission comes straight from its chairman, so if something like that is there … it has to come from the top management* [especially] *if they are keen to be something different* [then] *it would be done and they can figure out a way to make it economically viable.*
>
> [R] You stress the importance of top-level management and their vision and the economic viability of the innovation?
>
> [I] *Again you can say that external bodies like the government can step in a bit, but I think that is so limited, because what are the government or whoever going to do, if the top management are not keen to actually go in that direction?*

Excerpt from interview with Participant 15:

> [I] *Within an organisation, it needs two things from the people at very top of the company. First it needs their support, and then it needs financial investment … they also need to appreciate that some of their staff are going to have to take time to implement some of these, especially when they are new technologies, they have got to learn how to use it. I think that sometimes when you haven`t got a tangible benefit for it they are reluctant to put the time and effort and the money behind it, because they are not guaranteed a result.*
>
> [R] Who are we talking about? Top level management or the guys on the project level?
>
> [I] *Director level. You really need to make a strong business case to directors to get their backing to do it. I mean, for example we probably have got a lot of people in the company now who are itching to get to use some software that helps them implement BIM but the implementation is only goes as fast as the higher level management are allowing it.*
>
> [R] Why do you feel they are restricting it in some way - do you think that they are?
>
> [I] *They are only selecting projects one by one to start running at level 2, but they will only selected projects to run at level 2 where there is a business case, so either the clients are demanding it or it is a higher risk project”.*

Interestingly two of the directors interviewed (Participants 189 and 231) considered that implementation of innovation at company level occurs ‘bottom up’ rather than being pushed from top down and preferred to focus on project level innovation implementation.

Excerpt from interview with Participant 231:

> [I] *If you do it top down, you never get buy in. The few bits that I have done, I have got buy-in from the guys on the project and then we've kind of rolled it out as a company … If you just tell someone, that's the software you are going to have to use, it doesn't really work. They got to see the reward and they have got to see that there are benefits for them … otherwise it's just sits on the desk, or site in a drawer.*
>
> [R] So you are saying as a director yourself, that [in] communicating the message to the guys …that you are pushing it down.
>
> [I] *Well, even though I'm at director level … it is always project specific … if you have that approach you [will] do it on one project and* [if] *it is a success then people generally want to be… you know everybody wants to be part of the success".*

From my experience … I think it has to come from the bottom up, because that's where basically where the strands of innovation are coming from, from the subcontractors. The guys at the top who are running the region aren't really in touch with that kind of grass roots level you know" (Participant 189). This grass roots view was echoed by a middle management research participant who also considered other drivers of innovation at project level: *"Innovation should be driven by the client and design team … but again it's subcontractors and material suppliers that are bringing these new products to the market"* (Participant 123).

There was also the view that echoes Winch (1998) in that both dimensions are equally important, although the proportions tended to vary between each participant such as "*I think it is 50/50"* (Participant 203) and *"it is probably about 25% top down and 75% bottom up.*" (Participant 210). Again, a lengthier excerpt is used to highlight this:

> *"I think it's a bit of drip-feeding from the top down and I also think that it is the frustration and the anger from the bottom up that there needs to be a better way of doing things. I think that managers in the middle, kind of need to hear the pains from the people on the ground who are trying to do the work and the*

> *confusion and, at times, the anger and frustration, and obviously* [they need to] *hear from the client side and the top down … so it's a bit of everything really, but I think that the people at the lower levels who are trying to say 'what can we do to improve it?' and I think it really has to be from the top down they are the ones who are going to have to sign the cheques, they're the ones who are going to buy the software and invest. They are the ones who make the decisions about the training, and I think it will be sold to them on cost savings, reduced risks, time efficiencies and better profits. Because at the top echelon of these companies* [they] *are trying to look after their shareholders and if they are saving money and making money … so I think it is top down but it definitely needs understanding form the middle level, even if the top level don't totally understand how it works but just know that there is less costs saving, mid-level will be implementing it all and ground level will be hopefully very happy that they know what they are doing and just want to crack on and get the work done"* (Participant 245).

Participant 246 also considered a further dimension - the type of company ownership, by drawing upon their working experiences and offering insight into the contrast between privately owned and publicly limited companies (PLC). This participant highlighted how innovation adoption decisions made at board level of privately owned companies are quicker and more responsive than those in PLC companies where other stakeholders involved in decision making may be required to approve or provide any financial investment or may restrict these financial investments because of a need to ensure certain profit levels are maintained.

Several participants noted the need for demonstrations to see the benefits of an innovation: *"There definitely needs to be some kind of demonstration, it's a visual thing … piloting"* (Participant 100). However, whilst demonstrations may be useful, it was found in the analysis of the explanatory questionnaire phase of research that the more hands-on approach of piloting or trialling was a key concept, and that for 4D BIM to diffuse more rapidly potential adopters have to be convinced that it can be trialled in a safe environment prior to use on a live construction project. Particularly insightful were those interviews that considered trialling along with the twin impacts of organisational attitude toward risk (Larsen 2005; Larsen and Ballal 2005) and low profit levels (Reichstein, Salter and Gann, 2005; Manley and Mcfallan, 2006) and their subsequent impact upon innovation diffusion. This came from Participant 41:

> *"We tend to want to trial them* [innovations] *on one project … we get this long cycle where we develop an innovation, we trial it somewhere and that project is probably going to be between 12-24 months, and only at the end of that do you gain the learning and then they are probably going to want to trial it on 4 or 5 [other] projects simultaneously. You get to the end of those and then it may get rolled out across the business, so you are looking at anywhere between 2-4 years to deliver an innovation across the whole workplace. The reason that that scenario ends up happening, is that profit margins are quite low in terms of percentage profit, and we are a very risk adverse industry based upon that, and those two things combined with the long lifecycle means that innovation is … it's not stifled but it is extremely hard to drive through, and because we've never done dramatic change its very much tiny incremental steps because of the risk involved it does tend to slow the effect and that's an industry wide thing".*

This participant is notable as they have spent separate periods of time working for contracting organisations delivering projects, but also worked for a 4D BIM software vendor actively promoting the innovation[1]. As such they were well positioned to consider how receptive the industry is to the promotion of innovations from multiple perspectives:

> "[Vendors] *spend a lot of time building up and giving an impression of the provable benefits, and the construction industry tends to take them very much with a pinch of salt, and wants to try them themselves. The best way I found across both ways is, you end up trialling on a single pilot project but setting very clear goals of 'this is what success/ failure looks like' and you have to score it, but it has to be very criteria driven, especially when you get into the realms of BIM as with a lot of* [similar] *innovation, some of the benefits are intangible, because the mistakes and errors never happen, so how on earth do you measure something which you have never spent, or planned to spend in the first place? that gets quite interesting. For me* [the answer is] *its - trial it, but if it meets the measured criteria then it works, there is no need for that middle second phase of 'well let's trial it across 5-10 projects now'. One of the last experiences that I had with* [Software Vendor] *was we went from doing a couple of very small pilots in isolation to then doing a sort of … they called it an extended pilot [but] it became the beginnings of a mass roll out, although it was structured in such a way if that had failed, as part of the larger pilot the roll out would have stopped at the 10 projects. The minute it crossed the 10-project threshold it became 'this is the way we are doing it, the way it is going to happen from this day forth'. In reality if you trace it back it was because of this 1 pilot project that had been successful".*

1 Participant 41 was also named as a change agent by one of the other interviewees.

8.5 The impact of BIM

Earlier sections of the work identified the impact that the quality of production information has upon the planning process, and how poor quality project information contributes to the time predictability problem. Participants were asked about two specific innovations BIM and 4D BIM. First the Participants were asked:

> ***"Has BIM impacted upon the quality of production information?"***

Some participants did not consider that the quality of information has changed: "*Not that I have come across"* (Participant 245), or: *"I wouldn't say so yet* (Participant 189). Even when holding this opinion, participants were able to acknowledged some of the benefits of BIM such as the conceptualisation of design (Hartmann and Fischer, 2007; Huang *et al*., 2009): "*I would say no ... apart from the visualisation or the visual impact of things being drawn in 3D that does help people get their head around what they are actually trying to build"* (Participant 100).

Problems of the receiving design information in BIM format early on in tender processes were noted: *"I've done a handful of tenders now, where we have managed to get the BIM model out of the design team who can be reluctant to give it to us anyway* [and] *I wouldn't say that when you then look at the drawings for those particular projects, that it [BIM] is any better or any worse than a normal project"* (Participant 189). Projects where designs are issued in BIM formats appear to be exceptions rather than the norm as evidenced by the exchange between the researcher [R] and interviewee [I] in this excerpt from the interview with Participant 123:

> [I] *There are some projects where the quality of the information is getting better, but is it the right format that we require? I think probably 70-80% of the projects that are coming out to tender in the market, there has been no change*

whatsoever. People are very still stuck in the traditional methods. We are just receiving PDF copies of drawings or in .dwg files - if we want the Revit files we have to go and ask for them and often we are not getting them, we are refused which makes our lives very difficult when we are trying to bring BIM techniques to our bidding [processes].

[R] So there is no [general] change in the actual format of design issue, but the [BIM] ones that you are managing to get, do you believe the quality of information is improved or is just the same but in a different format – apart from the 3D aspect obviously?

[I] *Yes, some of the information is better but we have got a BIM coordinator and she analyses all the data, and she very rarely gets the level of information that we require and she is still bringing together, the architectural, structural and engineering, the M&E* [information] *and federating them together into one model, because on most tenders we still need that doing." (Participant 123).*

This indicates that even when BIM designs are being issued, contractors may have to alter and align their usual practices to yield the benefits (see Arayici *et al*., 2011) resulting in additional work, a common concern amongst participants. To be able to get the required information in a format useful for construction purposes, contractors may have to take a greater lead in the design coordination process by aggregating design information issued in model format, which may require additional resources or incorporate additional steps into design coordination processes. Participant 245 considers the unintended problems generated by people, and in line with processes described by Alwan and Gledson (2015) discusses having to repurpose information to ensure that necessary constructability information is contained within the BIM:

"*The information is only as good as the people putting it in, or* [who] *understand it's use and role of filling in all of the fields correctly and consistently … I've only seen* [models] *where I have had to go back in retrospectively and add site meta data and classifications to make it easier to use so I'm probably going to say that it is still very early days. I would not say that* [there] *is mass major impact … I don't [think] that that architects are really* [mass] *producing it and in their mind, you know they have got to design something but they are not thinking about how it is built, but from our point of view as planners we know to take that design and we know how it is built, but to get the two to meet you have to have this middle ground of sharing information and the quality of the data … I still don't think it is there, that's my understanding"*.

If information is received in the required format, problems remain with getting BIM down to site level: "*I think it* [quality] *has improved for the clarity of how things* *should be built, from seeing the models … It helps me as a planner, but maybe not on site, as they still work off traditional drawings … that are generated from the models* [which] *still have the same level of information*" (Participant 195).

Those participants that did believe that it has impacted positively upon the quality of production information usually focussed on coordination aspects and benefits of being able to detect and rectify clashes virtually (Li, Lu and Huang, 2009; Eastman *et al*., 2011) which have led to fewer clashes overall: "*Even though we have only done 2 BIM projects to date they have improved … already we have seen that the quality is better … certainly the integrated design is better - there are less clashes*." (Participant 231) or being able to provide information in the required format:

> *"When there are fully federated models it definitely improves the quality of the design that`s turned out, and also the ... I am using the M&E services design as an example here … traditionally all you used to get was a lighting layout, a fire alarm layout, a security layout, the assembly layout, a ventilation layout, and by having all of those in one model, a builder wants to have a ceiling layout with all the services in, and he does not want five drawings of all of those services in the ceiling, so being able to model the building services in a model you can print out pretty much what you want from a model. It allows you, for example, to print a reflective ceiling layout that has all of its services penetrations in, so it is a more coordinated approach"* (Participant 15).

As evidenced in an above quote from Participant 245 it was felt by others that, despite the benefits and efficiency gains, people continuing to want to work in traditional methods make any necessary transitions difficult: *"It has totally revolutionised the way that information is produced … it is changing what information is produced and what information is sought as well. It's almost construction reinvented and done in the proper manner … with BIM there is all of these things, there is the huge potential and possibility of doing things in a better manner but if people are not keen to use it, then nobody can help them"* (Participant 193).

Participant 210 put people problems down to the variability in the *fields of experience* between different construction professionals and their individual preferences for receiving design information:

> *"It is easy to say yes, but I think what is different is an increase in representation of information. It has helped with the low hanging fruit of efficiency gains and everything with the management of iterations. I am apprehensive in saying wholeheartedly 'yes' because, has it really? You can argue that it has by certain factors, so in comparison with vector based design where you are now going to object orientated design, then, yes it has, but in terms of quality production information it's about representation to the desired recipient. I could say that you can engage greater with the stakeholders which informs decision making, I'd say it is better so* [the design] *can be more easily understood so it is not that esoteric …* [but] *I'd also say in terms of construction you've got contractors, you've got sub-contractor who are used to seeing deliverables in a typical form and then saying something different and it takes greater time to comprehend to some extent because they need to find the boundaries … it is about different fields of experiences, and it's not just ones professional background it is more so, how similar are the fields of experience between the information exchange participants?"*

Learning curves were also a theme picked up by Participant 203 who thought that wanting to investigate for too long a period before adopting also hindered the adoption process:

> *"It has* [improved quality, but] *I think, in some respects it been a little bit of a hindrance whilst people are getting their head around it. I think a lot of people have been looking into it more than they have needed to, but it definitely has had some benefits on* [regarding] *quality … certain experiences that we have had is that a lot of guys have tried to look into it a lot more, and as they have been getting used to all the process and the data, the level of information, I think they've … not done themselves a disservice but they have confused themselves quite a bit, like some of the designers when they have been asked to put certain levels of information in".*

Two separate participants used a jigsaw puzzle as a metaphor for discussing the consequences of the quality of information that BIM can provide, in what Rekola, Kojima and Mäkeläinen (2010, p273) refer to as "*the problem of incomplete information*". Participant 41 considered:

> "*It's a mixed answer really, yes and no. Yes, in that it gives us more information. Sometimes that is a good thing as you can use it to make more informed and better decisions. The problem that arises with that is that not all the information is received at the same time or moves into production at the same rate which often means that you might previously with traditional methods have one or two pieces of the jigsaw and it was easy to see how they fitted together. When you start to get more information streams you start to have five or six pieces of the puzzle and what you might find is that three of them join to form 'the bottom left hand corner' and you have got another three sort of lonely pieces that whilst they are*

> *part of the bigger picture they don't necessarily attach directly to what you have now and you are still waiting for a few bits and pieces in-between to arrive. So sometimes it means that you probably led ourselves down a lot of avenues that we wouldn't necessarily have gone down … we go down and we investigate them and sometimes they don't yield any benefit. So yes, on the basis of more and even better information, but a lot of time can be spent looking at issues that are actually minor, as their risk level is low, so is there any necessity to go down that route?*"

Similarly, Participant 246 discussing the need to get commitment and 'buy-in' from all members of the project team when stating, "[It's a] *classic jigsaw puzzle type scenario, if all the pieces aren't there you can't get a clear picture … that's the way BIM is starting to look*".

Participants were then asked:

"Has BIM impacted upon the planning of construction work?"

Most agreed that BIM had impacted upon the planning of construction work but in terms of actual 4D BIM use some participants considered that it was used more on: "*bigger and more complex jobs*" (Participant 100) and that: "*for the bigger projects,* [such as] *Terminal 5, it's really important*" (Participant 245). General observations on diffusion were that: "*it's been a bit of a slow uptake*" (Participant 203). Some participants from adopter organisations noted that 4D BIM was being treated as a kind of 'added value' service, only being provided as an additional service if specified by the client team: "*At this stage 4D BIM is dependent on the Client buying into the concept; not de-facto given in our typical workflow. Still seems to need mainstream acceptance*" (Participant 184). On one such project, Participant 189 discussed making use of a BIM and the quality of project information provided when using the model to help with the initial activity identification and methods planning stages of the planning process. As he was only required by the client team to return a traditional deliverable - a tender programme in Gantt chart format, that is what the organisation chose to do rather than produce 4D output: "*When I was developing the program I did look at the model,* [but] *do I think that I developed a better programme for having looked at the model? I have to say, I don't think I did. I'd like to say that I did, but I genuinely don't think that I found anything in that model that I didn't get from the drawings*". Similarly, Participant 15 noted that his organisation could provide 4D output, but were: "*working purely based on demand. They are only providing it if it has been specified or clearly asked for*"*.* Providing additional comments on the questionnaire, Participant 166 added, "*the decision to use 4D BIM has to be made on a project by project basis. Our company has implemented it on certain projects (retrofit projects) where the ROI could justify the additional BIM resources & man-hours*"*.*

However, several participants who work for early adopter organisations that had implemented 4D BIM and used it on multiple projects provided numerous examples of the benefits, which included using it: options analysis; to provide the client with alternative proposals; to successfully resolve logistical challenges on site; to arrange early procurement of materials and reduce programme duration. One such response was provided by Participant 193:

> "*We use it greatly to look at the quality of our programme, just to make the programme robust enough so that, when we go to the site we have something that is workable rather than something of an assumption that "this will be done like that, that will be done like that, and this will go in a good manner". We can't accept it like that. I was plotting a decant* [strategy for an existing] *building that was two foot away and we know that the decant will be critical for the main scheme as it is going up, so we get accurate site information about what is going to exactly happen and what we are going to face on the site, and the same sort of things you can use in every different department. Like if the commercial guys are using it … if the model is produced to an accurate standard they can look at the exact quantities and they don't need to create the bill of quantities. And if we don't generate the schedule straight away they would have to sit for weeks to create these quantities and they won't be as exact*"*.*

Researchers have identified that 4D BIM can improve communication of the construction plan by helping narrow the communication gap (Liston, Fischer and Winograd, 2001; Heesom and Mahdjoubi, 2004; Dawood, 2010; Mahalingam, Kashyap, and Mahajan, 2010) which should reduce transactional distance between actors (Moore, 1993; Barrett, 2002 as cited by Soetanto *et al*., 2014). However, the literature also revealed that historically the most frequently used communication formats for planning were bar charts produced from CPM scheduling software. One flaw with the use of bar charts was identified in an early interview with Participant 19, undertaken at the outset of the exploratory questionnaire who also advises on one of the major strengths of 4D BIM innovation: "*Nobody really looks at a programme do they? No, but they would look at a* [4D] *video of how the job is going together and they would understand it … because it's visual, everyone knows what the building looks like when it goes up, and what it will look like half constructed, but if they looked at the programme they wouldn't really have that visual image in their head"*. Participant 41 considered that many construction practitioners have a kind of 'functional illiteracy' when it comes to interpreting the construction plan from a construction programme: *"When I was a trainer for* [names 4D BIM software vendor] *my favourite question to ask* [the audience] *was 'who can read a Gantt chart?' and out of 10 people maybe 3 of them would put their hands half in the air and say 'maybe' even if you had a planner in the room they would sometimes be reluctant to put their hand up … the advent of 4D lets a lot more people engage in planning that wouldn't have done so previously…* [it] *allows a lay person to see the sequence and make a difference".* However, despite the communication advantages that 4D BIM innovation offers through better visualisations of the plan, the traditional lack of a feedback loop to aid communication comprehension still remains, as evidenced in the following exchange with Participant 210:

> [I] *In terms of construction I'd say that it* [4D BIM] *has increased the representation and visualisation aspects, but what is missing in every part of the construction, in terms of planning is the feedback. We don't … we take things for granted so we don't challenge anything … we talk about planning construction work about how it is about sequencing, but to be brutally honest we don't improve it, because the feedback, we don't find the feedback we just do it and say 'yes, I can see the plan, that is what I am doing' but we don't challenge that. We don't*

optimise the process, which BIM can do by increasing the representation for all stakeholders.

[R] That's good, I mean I read your additional comments on the questionnaire* [below] so I appreciate where you are coming from, and you have expanded on it there quite nicely, where you say, basically we are doing the same thing just in a better way, but we are not seeing improved results because we are not challenging it.

[I] *Yes, I mean what we can do is open the forum for other participants what is just fantastic, but to truly see the benefits and value we need to optimise it.*

Additional qualitative comments were sought in the second explanatory questionnaire, and many participants chose to focus on aspects of 4D BIM. Several of these responses are reproduced here that focus on communication (efficiencies and lack of a feedback loop); additional workload or resource requirements needed to produce and maintain 4D plans; and the commitment needed from the project team when delivering a project using BIM innovation:

- "*4D methods provide excellent means to communicate project progress and schedule to clients, which is very difficult with the traditional methods*" (Participant 177).
- "*I think 4D is most effective for those who have trouble interpreting the traditional Gantt charts. Also, a 4D schedule can be time consumer to produce and maintain. I believe 4D in construction is best used for illustrating complex construction sequences - not the entire project*" (Participant 187).
- "*In my experience the quality of planning produced may not necessarily be any better. The main benefit I have found is that it facilitates FASTER understanding of the building arrangement. I have perceived this 'shortcut' regardless of whether viewing a Revit model in Navisworks, hard copy 3D images or even traditional, hand-drawn isometric artists' impressions*" (Participant 189).
- "*I would say it is a good method of contributing to a common understanding of the process, however, there is an inherent need for*

feedback and iterations within plan generation to generate a common understanding, engage all participants and reduce ambiguity through all tiers [of] *the project supply chain. 4D BIM contributes to this by allowing it to be understood by a wider audience due to seemingly better representation of data. To sum up the general comments, one would argue, yes you can see items, you observe the construction sequence, however if there is no feedback and iteration it is of less value. Less sequencing more optimization*" (Participant 210).

- *"I'm not entirely sure what advantages in general we will gain from 4D BIM. I can see the bonus in visualisation when work winning; presentations to clients and where we have a project with numerous interfaces and operations, which need to be completed in a set sequence. Most of our 'bread and butter' works are less complex, so the need for 4D BIM, in my current opinion is less important"* (Participant 188).
- *"It is incredibly resource intensive to develop and then maintain a 4D model. For that reason, it simply isn't practical to do 4D in most cases. There is also a necessary change in the way construction planning and scheduling occurs to really take advantage of 4D. In nearly all cases, the schedule is developed using traditional means and then it is applied to a model. To do a complete 4D process, the schedule should be developed against the model and that simply does not happen. There is a lot of promise in 4D, but interoperability issues, resource constraints, and maturity of the products for 4D are still a limiting factor"* (Participant 208).
- "*4D is great, but it requires intense effort to create and update which makes it a proposition of: 'Is it worth the effort to create and maintain?' It is mainly used to win work but is seldom used as a management tool because of the effort required*" (Participant 163).

- *“The adoption of 4D BIM would greatly benefit the planning function. However, it requires buy-in from the entire project team and suppliers as opposed to the competency of a planner to produce a model focused programme”* (Participant 158).

Chapter 9: Explanatory Semi-Structured Interviews – Part 2

9.1 The Innovation Decision Process

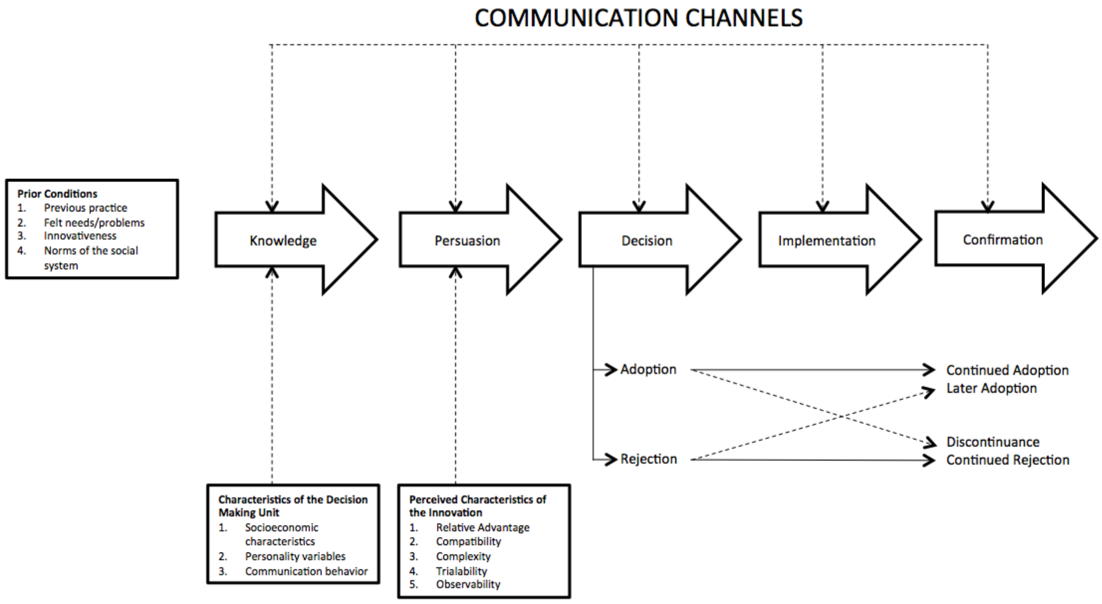

Figure 9.1: The innovation-decision process. For reference, identical to Figure 2.2

Rogers (2003) innovation-decision process model was previously described in Chapter 6. Participants were provided with the model and an explanation which were embedded as artefacts into the question list, and asked questions related to their journey through this process in relation to 4D BIM[1].

9.1.1 Knowledge

Participants were first asked:

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1 As each of the interviewees had already completed the explanatory questionnaire in advance of undertaken the semi-structured interview, they had already provided some data about the 1. Knowledge, 2. Persuasion and 3. Decision stages including 'year of first awareness' and 'year of first use', and the researcher could draw upon this data when tailoring the questions to each participant. For example, with questions about first awareness these were personalised like this: "*You identified on the questionnaire that you were 1st aware of 4D BIM in 2009 - can you take me back there and tell me about that - what was your initial knowledge of 4D BIM?*" and for first use: "*You identified on the questionnaire that you first used 4D BIM in 2011, After your first use did you continue to use or discontinue use it -Was there any initial adoption or rejection decision made after first use?*"

"What was your initial knowledge of 4D BIM?"

The behaviours of individuals can either be either active or passive at this stage with Rogers (2003) asking, *"which comes first, needs or awareness of an innovation?"* Despite the issue of construction project time predictability, very few participants reported being occupied in active information-seeking for a solution to this problem.

It was discussed how both Emmitt (1997) and Rogers (2003) recognise the importance of opinion leaders in a dual role as either a promoter of, or an impeder of innovation diffusion[2]. Participant 245 identified initial knowledge as coming through contact with an individual they later identified as a change agent. Conversely Participant 100 attributed the role of mass media through primary communication channels: "*it was seeing it* [4D BIM] *on, YouTube clips and things like that, and in* [the] *press it was starting to get talked about in magazines".*

Whilst all interviewees first became aware of the innovation through passive behaviours and chance, some saw the information as serendipitous and followed up later in the innovation-decision process with more active information seeking behaviours to satisfy their needs and interests. The most frequent mention of the means of first awareness was through teaching and self-study at higher education institutes (HEI's) with specific active information seeking behaviours being demonstrated. The earliest awareness from those interviewed was Participant 231 who recalled first exposure of this innovation when studying for an MSc in the year 2000. Participant 189 recalled exposure in 2004: *"I was doing my dissertation, which was on planning … and the 4D BIM element came up as a side issue for what I analysed then"*. Participants who recently undertook study at

2 In this way, opinion leaders act as 'gatekeepers'.

HEI's were consistent in identifying their first awareness as being between the mean year of awareness of 2009 and the median year of awareness was 2011[3]. Participant 15 who started working as a construction planner in 2007 and later commenced part time study and who identified the timing of his first awareness as 2011 acknowledged: *"My first knowledge of 4D BIM came through university, and then obviously through my studies I learnt what 4D BIM was and it interested me so I pursued it on my own … a lot of my first knowledge was through studies and self-interest, rather than being introduced to it by the company".* These active information-seeking behaviours from participants who studied at HEI's and therefore had higher levels of education, seem consistent with aspects of IDT that consider particular socioeconomic characteristics as determining the earliness of knowing about an innovation.

All participants recalled their first impressions as being positive toward the innovation. Visualisation benefits featured heavily in the responses. Some participants focussed specifically on communication benefits, and improvements in planning sequence, working space and movements:

- "*I got excited seeing it build up in 3D, and thought that the sequencing aspects of it was excellent*" (Participant 195).
- "*I thought would be useful communicating … to the client … what is going to be built and how it is going to be sequenced, probably to the project team as well - how we are going to plan it*" (Participant 193).
- "*I think it was mainly site logistics, that was certainly the way that I interpreted it, that was the benefit, of planning working space and organising the site*" (Participant 189).

3 This corroborates some of the findings within Chapter 7.

The only negative response involved the concerns of additional work that the participants would have to undertake, particularly operating within time constrained contexts. *"I thought that it would be useful but that it would be something that would possibly take longer to implement than current methods … It would create more work, take more time to use and to do on tenders"* (Participant 123).

Rogers (2003) identified three types of knowledge of an innovation: *awareness-knowledge* (what is the innovation?); '*how-to' knowledge* (how does it work?); and *principles-knowledge* (why does it work?). The responses have largely focussed almost completely on aspects of 'awareness-knowledge', although one participant noted a concern on 'how-to' knowledge on the returned questionnaire: *"There is very little information available (tutorials etc.) on the technical aspects of 4D sequencing and animations"* (Participant 155). This means that whilst awareness was facilitated through mass media, the actions of change agents or efforts on HEI's with potential adopters having to interpret what the benefits are, and what they would mean for their own practice, diffusion is potentially hindered by a lack of information about the practicalities of 4D BIM in these communication channels.

9.1.2 Persuasion

"What persuaded you to consider the use of 4D BIM?"

Persuasion is to do with the psychological involvement of the individual with the innovation. Perceived characteristics of 'relative advantage', 'compatibility', 'complexity', 'trialability' and 'observability' of an innovation play a role at the persuasion stage, and a range of responses involving these perceived characteristics were provided.

***Perceptions of the relative advantages of 4D BIM over conventional mean of construction planning*:** Relative advantages discussed included: making improvements throughout the communication process; improving construction planning through sequence optimisation, and; producing project time savings. In terms of improving the communication process some participants focussed on communication between contractor and sub-contractors:

> *"You can filter the model out to suit the trade contractors, so you if you are meeting with a specific contractor, you can just show them the elements within the model that are applicable to them. You can talk through those elements. I think that doing that not only enhances communication between everyone, but it can reduce scope gaps in procurement as well" (Participant 15).*

Other participants focussed on client team-contractor communications. Participant 203 recalled an opportunity to be able to clarify, then get approved a detailed construction sequence from the client: *"It was a case of wanting to enhancing communication with the client"*, whereas Participant 210 identifies the benefits of involving a wider range of project stakeholders in project decision making:

> *"the planning process … could be opened up to a wider scale population, so you've got, instead of the primary project team, you've got the secondary and tertiary stakeholders to which I think it is of greater value … It is about giving the right representation to the right people, and getting the feedback from that and improving it [the plan] and that is what persuaded me to do it."*

The benefits of sequence optimisation and options analysis using 4D BIM were considered: *“Planning the project out and being able to make it build itself up on the screen, so build it before you build it, in a sense … virtual build before physical build”* (Participant 195). Also, the advantages of greater programme validation and the ability to minimise instances of ‘knowledge leakage’ that usually occur in the traditional information transfer processes between contractors pre-construction and construction teams (see Anumba *et al*., 2002; Tizani, 2007; Rekola, Kojima and Mäkeläinen, 2010) were attractive to Participant 100: *“It looked like a good way of verifying the programme was right, I thought it would help to improve logistics on site and help with things like temporary works, scaffolding, curing times, drying times. it would help* [make] *the programme a bit more robust and … it helps the rest of the team gain from the knowledge that I’ve developed through tender stage and then pass it on to the construction team”.* 4D BIM was also considered to offer advantages in construction project time predictability regardless of project value: *“It doesn't have to be just for massive projects but it can be for smaller projects if the clients and the construction company understand what BIM could bring to them, the reduced risks and the time and cost savings”* (Participant 245).

Perceptions of compatibility**:** This was discussed by Participant 203 who revealed: *“It can be linked back to different methodologies; we can link it back to Last Planner”.* This is consistent with the analysis of the quantitative data which revealed that 4D BIM innovation is compatible with existing planning practices.

Perceptions of complexity**:** This was considered by Participant 15 who perceived his company to be a late adopter: *“I think that the company saw it as they just needed to get ‘3D’ right before they would even consider ‘4D’, which is* *why it has probably taken so many years to get to the point where they have become persuaded"*.

***Perceptions of trialability*:** Rogers (2003) acknowledges that trailing an innovation on a partial basis can help with resolving issues of uncertainty about the consequences of that innovation, and that, "*innovations that can be divided for trial are generally adopted more rapidly*". Multiple participants commented on the need for piloting or trialling the innovation across single or multiple projects: *"You do it on a test project, that's the best way to get the message across. Do a test project, get the success, bank the success and then roll out"* (Participant 231). 'Trialability' is a key concept for successful 4D BIM adoption and was discussed both in the earlier quantitative analysis stage (Chapter 7) and in responses to an earlier interview question ("*How are industry innovations best implemented?").* To recap: For 4D BIM to diffuse more rapidly, potential individual adopters have to be convinced that it can be trialled either in a safe environment prior to use on a live construction project, or organisational decision makers require trialling across a series of test projects which results in a lengthy time period between trialling and adoption. There is evidence to suggest that for such trials to be effective there is a need to clearly define criteria for success or failure and there must be a means of measuring the results of use of the innovation completion of the project.

Perceptions of observability: At site level, Participant 246 describes observing the impact of 4D BIM upon the project team and site workers when working on one of the first case study projects trialled by an organisation on a complicated project involving the construction of multiple buildings on the site: "*It helped break down the complexity of the two buildings on the programme … which made things a lot easier to point out to subcontractors* - [when] *they were going to be* *working in certain areas and who was going to be working around them".*

Participant 189 discussed observability in terms of how rapidly the visualisation benefits of BIM innovation has diffused into the tender practices of some of the larger organisations tendering for major projects. This has subsequently informed and raised the expectations of client teams:

> *"I'm largely on the work winning side* [and] *saw the benefits of it for tender competitiveness. I was getting feedback from tenders from PQS's and project managers and it came to a point where quite recently* [2014]*, it became apparent that if it was a large-scale tender for a scheme of any size, when you went to the post tender interview, it was almost expected that you would include, if not a 3D model, certainly images from that, it was almost becoming the point where they expected logistics and sequence plans to be in 3D not in 2D anymore. And certainly, for the post tender interviews we took a 3D model along, which we developed to show the site logistics and sequence, basically to demonstrate that we understood the works, we understood the problems and tried to find solutions. We thought it would go down very well, but the feedback was that the other three tenderers had something very similar. So, if you went to that interview and you didn't have something like that, you would look inferior at first perception even if your ideas were good. It was almost as if it was being expected of you".*

In addition to reviewing the impact of the perceived characteristics of 4D BIM upon the persuasion stage, analysis of the results reveal that an additional factor that influences persuasion can now be added to Rogers (2003) original model, which is the impact of *external agency* upon 'persuasion'. Within the UK Construction Industry, Government provides agency by combining policy, regulation and championing behaviours. Gann and Salter (2000, p960) identify that "*government regulatory and procurement policies have a strong influence on demand and play an important part in shaping the direction of technological change*". Aouad, Ozorhon and Abbott (2010) contribute that government construction policy dictates the diffusion of construction innovations. Caerteling *et al.*, (2013) argue that from the perspective of technological developmental policy, government should take on the role of champion, and Na Lim (2014, p551) agrees that the role of government should be "*more than an enabler of construction innovation*" they should be a marketer proactively involved in the promotion of construction innovation. As discussed in Chapter 1, there is now policy for centrally procured public construction projects to be working at BIM Level 2 (BIWG, 2011; HM Government 2011; Succar, Sher and Williams, 2012) and BIM is an innovation which has been both actively championed and marketed by UK Government in the form of 'The Building Information Modelling (BIM) Task Group'. Despite these efforts however, Participant 189 highlights: "*there are very different definitions for what Level 2 BIM is anyway*", and Participant 15 argued: "*there is still confusion over whether Level 2 actually includes 4D BIM*". Nonetheless Participant 231 reveals how the impact of regulation, policy championing and marketing behaviours of BIM by the Government dictates and incentivise the economic activity of many organisations working within this market environment: "*[in] the company I work … 90% - 70% of our work is RSL* [Registered Social Landlords] – *central government* [there] *is the threat of, you know – you have got to be BIM Level 2 by 2016, that's the driver, absolutely no question about it"*.

9.1.3 Decision

> ***"Was any initial adoption or rejection decision made after first use?"***

This stage in the innovation decision process is when decision making units either: choose to trial an innovation on a partial basis; make a conscious innovation adoption decision in full; make a conscious decision to reject an innovation after consideration of adoption (known as *active-rejection*); never truly consider adoption of an innovation (known as *passive-rejection*); or adopt an innovation then subsequently reject the innovation either actively or passively (*discontinuance*). A Chapter 2 endnote advised of one of Emmitt's (1997) contributions to diffusion theory, the concept of *postponed adoption*. Here, innovation is not immediately adopted or rejected, but knowledge of the innovation is retained for purposes of future application. This concept is considered relevant to this work, as adoptions of many construction process innovations are considered to be about waiting for the right project, or completion of an existing project before subsequent deployment.

Several participants working for large organisations reflected on their experience in trialing 4D BIM: "*The initial decision was to adopt it. It wasn't ever rejected*" (Participant 41), and: "*we must adopt this, this is where technology is heading*" (Participant 246). Participants who work for large companies but weren't involved in trial projects reflected on the adoption decisions made: *"They definitely said yes, we are going to adopt it"* (Participant 203), *"the decision was made that it was useful and that we would develop it further"* (Participant 123), *"definitely the corporate decision was to adopt … Its very much in its infancy … but there is definitely a corporate decision to commit the resources and the time necessary because of the recognition that it is something we need to do to remain competitive"* (Participant 189).

But not all large companies made clear adoption decisions. One individual who was first introduced to the innovation at a 4D BIM Workshop facilitated by the researcher, and who wished to adopt in such an organisation explained their experiences: *"It definitely wasn't a rejection, but it was very, it was almost an 'arm's length' thing, they kind of just let me get on with it, they paid for the software and the course, and it was just 'oh yes, that seems like a good idea' but it was very early days for me so I'm still learning and so it wasn't reject outright, but it also wasn't adopted by the group"* (Participant 100). Whilst this individual could be considered to demonstrating active information-seeking behaviour, his organisation could be described as having made a 'passive-rejection' decision, albeit with the possibility of 'later adoption' occurring. This is consistent with one of the findings from the explanatory questionnaire in that even when a clear adoption or rejection decision has not been made, there is still more likely to be personal use of 4D BIM innovation within larger companies.

Similarly, Participant 195 demonstrating active information-seeking behaviour, and working for a medium sized company, discusses cost as a barrier to innovation adoption. He advises how his organisation acted in accordance with Emmitt's (1997) concept of 'postponed adoption' and how originally the company only considered adopting 4D BIM innovation as a specific additional service if specified by the client team. This is evidenced in the following interview excerpt:

> [I] *I was trying to push it since probably 2010 in our office, in our business, but it* [the decision] *was purely on cost because the software [was] £6,000 for a license.*
>
> [R] So the cost was prohibitive?
>
> [I] *Yes …. had it been needed at the time, the director said "we'll press the button, if its needed by the contract, and we will build it into the cost, but if it's not needed* [specified by client] *…" Obviously, they weren't going to look to do it.*
>
> [R] So you have played about with it a little bit internally, it has not been rejected but the [adoption] decision has not been made for those reasons – it hasn't been implemented in your practices or in your organisation by the sound of it?
>
> *[I] It has now. We have literally just bought* [names substantially cheaper software product] – *we have paid for 3 licenses.*
>
> [R] Have you used it on a project yet, are you just trialing it?
>
> [I] *We have bought the software and we have bought the online training, and we have had the software loaded onto a machine and we are just about to set a date for the online training, because we have one job on the go that is just about to run with … they are going to try to push BIM principles within the job and then we are going to start on that one".*

Participant 245 discussed the ability of small organisation to operate more flexibly, after witnessing a clear adoption decision made by the company principal who was also first introduced to the innovation at a separate 4D BIM Workshop facilitated by the researcher: "*After first use of it on the training course he went on, it was an initial adoption* [decision]. *For him it was quite clear because he ran the company, it's a small company, it's something* [decision] *that you can make quite quickly".*

One of the only participants who did not consider the question solely from an organisational level was Participant 210 who discusses making the decision to use 4D BIM innovation on a project by project basis, because of concerns over value generation, and the capabilities of individuals working with the innovation across organisational boundaries in a TPO:

> "*The decision to adopt was based on the relevant and relative maturity of the team, in the sense that on any project I would judge it by the value proposition it provides. It might add tremendous value but it is only dependent on whether that is offset by the learning curve or whether you have got the right information from the deliverables from the project team. If I didn't have that from the project team I'd consider it but I'd be apprehensive and may not use it. It's* [about] *the relative BIM maturity, in terms of the participants so not that everyone needs to be at a high level, but that* [everyone needs to be] *on an equal level, so that everyone understands what everyone does".*

9.1.4 Implementation

> ***"Were there any notable issues around the implementation - when it was put into actual practice?"***

A range of discussion points were raised by participants. A typical process of trialling the innovation on a partial basis and the reasons for doing so was described by Participant 203:

> *"It was a case of enhancing communication between me and the planner. Because I'm not a planner, so I wasn't fully aware of what she was trying to get over, and I thought, "well if I don't know, then the client is not going to know". He* [client] *wanted to see it built and there was a couple of complex parts of the build in a really awkward location that we wanted to try to identify, so we started to just take it a little piece at a time and not try to do it all, we just do a small little section and then build on it from there, and it seemed to work"*

The challenges of organisational adoption were apparent in the consideration of the additional time and effort needed to undertake the planning process when using the innovation. This can be considered along with the unwillingness by some practitioners to consider adoption of the innovation: *"I think people are still quite wary of getting involved, and in a way they are scared of stepping outside of their current bubble*" (Participant 123), and: *"I think there are still people, planners within the organisation who were not too persuaded by it and they like their old* *way of planning"* (Participant 245). If this occurs, an approach taken in some organisations is to have an additional level of employee resource involved in producing 4D planning output: "*the biggest difficulty with it is that it became quite time consuming to link a programme to a model … it became very much a specialist trade and was undertaken by a 'digital engineer' … but because it's become more widely adopted its now starting to become mandated that planners will get appropriate training and appropriate software and planners will start to it themselves*" (Participant 41). In addition, the issue of programme complexity remains key issue as evidenced in the following exchange with Participant 193:

> [I] *One of the challenges is, there is such complicated logic to the programme and we have to try to replicate the programme granularity exactly as it is in terms of visuals for the 4D model, it is going to be a significant challenge in terms of work, and whether that is of value for the practice, so it is always about figuring out what is valuable for the practice and what will bring value to the project, and then focus on that reality and leave the rest.*
>
> [R] You mentioned granularity - on a typical construction programme that you have been dealing with - how many tasks would you say there are?
>
> [I] *So many pages, it is huge isn't it, the number?*
>
> [R] Thousands?
>
> [I] *Yes.*

The issue of having adequate and appropriate resources to be able to produce 4D planning output was of primary importance to Participant 183, a regional planning manager responsible for a team of planning practitioners who highlighted this in the following exchange:

> [I] *My issue with it is that we have got limited resource in planning and for the job to be finished on time and for everything to run smoothly, there are things that we can't do without, and that's like programming, planning in terms of Gantt charts, in terms of procurement schedule and monitoring of those documents on a regular basis to flag up where things aren't going well. To a degree BIM obviously has a big part to play in that, but we can't do without other things, and those things should come first. That's my concern, I think the 4D element of it is great, I think its unkind to say that 4D is a 'nice to have' because I think it's a lot more than that, but it comes a pretty poor second to those fundamentals things that must be done.*
>
> [R] You have expressed that on the questionnaire (reads), *"…despite its obvious advantages I still view it as largely a 'nice to have' rather than essential. I do have*

some concerns that it could potentially distract busy planners from carrying out their key/essential traditional duties for somewhat limited gain"

[I] *But now you've got this learning curve they go through before they become proficient at it and we all start seeing the benefits. Having said that with my experience in the work winning side of things, I don't think it is an option [not to adopt], I think we've got to make progress because if we don't … and then there's obviously the public side of things next year [2016] where it's not optional as well, so there some sides of it where it a 'nice to have' but it's probably the wrong phrase for me to use, I genuinely don't think that, I do think it has a huge amount of benefit to deliver but I still believe that you've got to get the fundaments right.*

[R] Maybe it is the fact that resources are limited – maybe it they weren't limited; you could do these things?

[I] *That's exactly it.*

[R] That goes back to one of the earlier questions about the structure of the industry – most people respond with 'low profits', but it all kind of stems from there.

At individual user-level, the perspective was that being directed to adopt before having the appropriate, hardware, software and training is problematic, *"It was quite a hard process to go through … the initial approach was rejection because we couldn't use what we wanted to use because we didn't have the facilities* [hardware and software] *to do it, so it almost became a throwaway but as soon as we got that* [training, and new] *hardware and software to utilise the function of the tool … we wanted to adopt it, we were raring to go … it was new technology that we knew as engineers was going to help us out"* (Participant 246).

Participant 189 also considered the potential adopters 'user experience' as a key aspect of innovation-adoption, particularly in the ease of use and user interface of the software aspects of 4D BIM innovation and in the quality of the output of construction plans in 4D formats:

"*I was comparing this to when computer software came in to be able to draw programmes. When I started doing that in the late 1980's/early 1990's, we used to hand draw programmes and I used to enjoy that process, and then gradually computer software came in, and the very first bit of computer software … you forget with programmes that a lot of it is about how it looks. If it looks good and if it is easy to read and you are not struggling to understand it, people are more likely to use it. Otherwise if it looks horrible and is difficult to read, people are just going to stick it in the draw and try to forget about it, and that was almost the way*

> *it was when computerised* [scheduling] *software came out initially it was a system called HORNET which was bloody awful and this was pre-Powerproject. It was horrible. There was a long time when we didn't want to do it, and we wanted to carry on hand drawing stuff, and then gradually it changed and the presentation improved a bit and we took it up."*

This resonates with the research findings of Hartmann and Fischer (2009, p353) who reported that "*user-resistance is not always a negative barrier, but oftentimes a necessary and important part of a Construction IT implementation*" - quite simply, feedback from users can aid further development, particularly of technological innovations with their frequent updating and versioning of software can be part of a going process.

In terms of adoption across organisational boundaries, participants identified issues with 'silo-mentality' (BIWG, 2011; Fellows and Liu, 2012), and problems with the sharing of design information in BIM formats:

> *"We had team members who were set in their ways, and if they are not willing to share the information then you can't make them. If that information cannot be shared in all the formats, then you will miss all of the benefits. So what we had was two disciplines who were willing to share information but the third one wasn't. Again, it was similar with the costs as well, and that is purely because they were apprehensive about their own capability. They were just unsure and they didn't want to share because of embarrassment I suppose, but … you could argue that, they won't share due to negligence potentially* (Participant 210)

Additionally, the consequences of some team members wanting to keep using traditional ways of working were addressed: "*What we have seen is that the models are only coming in as structural models or architectural models, I haven't had one model yet which has been integrated with the whole package, so all I'm managing to do is 'draw' a* [4D structural] *frame programme … unfortunately I can't go from the foundations straight up to the project finishes*" (Participant 100).

Rogers (2003) discusses the concept of 'reinvention' of an innovation, which is the "*degree to which an innovation is changed or modified by a user in the process of its adoption and implementation*". In terms of reinvention the focus was greater on BIM rather than 4D BIM, more specifically the effort in having to repurpose the fidelity of the information received in model format from the design team to structure it in such a way that makes it fit for purpose to be used in the 4D planning process:

- *“We had some issues from a technical point of view … I wouldn't say the models are particularly well spec’d for a BIM project. We're going through retrospectively and breaking them down – say for example when the designers have put in a floor level, we know for example that a floor wouldn't be built in one go, it would be built in sections, a concrete floor would be built in sections and it’s how you help designers and architects to actually break that down and help us to work together and that really where I think we are struggling… as far are architects are concerned once they have ‘built it’ [designed it], off they go… in our company we don't have 3D designers so we actually to send it back to them or we ask another company to split them up as we need to.. so, the floor might be built in ten concrete sections and we will ask them to create the model in ten sections … that is some of the issues that I’m finding”* (Participant 245).
- *“It* [Model] *is not split in parts that we ideally want to match in with the way you are going to build the building, currently our procedure is that we get the model, we sent it down to the BIM team in* [head office] *and there is a bit of a coordination exercise that goes in in order to tell them how we want it ‘chopped up’ for want of a better term and then we get it back, and then in theory then its ready to be able to then link it to the programme activities”* (Participant 189).
- *“One of the project they* [company] *have trialed, they found a lot of the same issues that I did … it wasn't very user friendly, they didn’t have a feature to sequence building elements, so you were relying upon the*

designer to model the building as per the build sequence, which they will never get 100% right … I would say that the granularity of the model was the big thing [and] *there was nothing you could do about it, if the model was modelled that way you had to programme it that way*" (Participant 15).

- *"The way that the model is structured is going to be the big thing … the way engineers and architects have envisaged the sequence"* (Participant 231).

One of Rogers (2003) key generalisations is that *"a higher degree of reinvention leads to a faster rate of adoption for the innovation*", and that "*as a result of re-invention, an innovation may be more appropriate in matching an adopter's pre-existing problems and more responsive to new problems that arise during the innovation-decision process*". In terms of 'reinvention', in successful adoptions of 4D BIM participants were able to comment on its multiple users: *"it is not just used by the planners. It is also used by the construction managers, and it is used by the commercial guys, it is used by everyone"* (Participant 193), and multiple uses:

> *"It is used by different people for different purposes, isn't it? Like the project leader could communicate with the client what the programme is like … for example, we had a road out the back and the client was quite keen to keep it open all throughout the project, now because we have shown him the process and how key it is for us to have full access to the road, through the project, we have shown him visually they have actually granted us 9 months-worth of road access now, so it is quite useful to be able to demonstrate such things" (also Participant 193).*

9.1.5 Confirmation

> ***"Has any confirmation since occurred to reinforce the adoption or rejection decision made since first use?"***

IDT identifies that messages of reinforcement about the adoption or rejection decision made can be sought during what is known as the confirmation stage, and that decisions may be reversed if conflicting messages about their decision are received. At the time of the interviews none of the participants identified any reversal of previous adoption decisions and no rejection decisions were reported. All participants were enthused about the possibilities of 4D BIM, offering examples of practice where confirmation of adoption could be justified.

Participant 193 advised how the use of 4D BIM planning identified that, to achieve project success an alteration to the original site layout and logistics strategy was required which meant both an increase in the number of cranes used and optimised use of them:

> *"the project* [originally] *started in 2008, and there was a construction plan, and all the time there was* [planned to be] *3 cranes and there are now … once we had new construction managers and they started looking at it in detail* [using 4D BIM] *… on the project and there are more than 2,000 precast panels, and just to lift them off and put them into place and if we are going to use 3 cranes it's just not going to finished in the stipulated time, so we have change the number of cranes and now we have 4 cranes, we know, 'what is the type of crane', 'what height it is going to sit at', 'what tonnage it is going to lift' and 'where are the pick-up points', … All those kind of details – we have looked at it in detail and then we have developed the model into different zones and started asking the planner to use and to defend their programme to see whether something is safe and again coming back to the robustness of the programme at that stage"*.

Participant 41 added, "*I have seen so many potential disaster scenarios that have been avoided by using 4D planning … there have been so many justifications for its use".* This participant was also able to comment on the ongoing technological development of the innovation: *"the software has moved* [even further] *forward*", by providing several examples such as: the automated quantification of model elements to inform task durations; the use of QR codes to track deliveries of on-site components; the increased ability to record progress and assist with QA processes; and the automated linking of model objects and construction tasks, a process which was previously undertaken manually and was described by Tulke and Hanff (2007) as a major drawback in the process of creating 4D planning output.

Participant 246 discusses 'confirmation' as being a "*lightbulb moment*" when detailing his involvement in a subsequent project that followed his earlier involvement in one of the company trial projects, and how the use of 4D BIM resulted in a proven shorter programme duration that increased construction time predictability. This participant details how the contractor was to build multiple new build hospital blocks whilst working on a site that included existing hospital facilities. The original plan was to sequentially move the work from block to block, but the use of 4D allowed them to more effectively plan the movements of mobile cranes so that they could see exactly where these cranes would be at particular points in time and use these opportunities in order to operate on multiple work-faces on different blocks in adjacent areas at the same time:

> *"It was the realisation of how it would help us in the sequencing of the blocks. It then meant that it* [4D plan] *was able to show the client exactly what he was after in the time sequencing of things, of when he was going to get early possession, but it was also the fact that we were working around and working within areas close to the* [existing] *buildings and that was the 'lightbulb moment'* [in the team] *of thinking 'Do you know what? We are getting this right', going into this much detail and this much depth, although It is quite difficult at the start … it meant that the client and the users* [the contractors project staff] *were going to get out of it, the benefits. It wasn't just 'we are just doing a showpiece' it was that we could save time on this* [project]*. We were saving money by doing 4D planning".*

9.2 Communication channels

IDT explains that external communication channels are more important at earlier stages of the innovation adoption process, and internal near-peer communication channels are more important at the later stages. However, analysis of the data collected using the explanatory questionnaire found no statistical significance in tests of association between communication channel preferences and adoption levels of 4D BIM. In the interviews, participants were asked to expand on their answers regarding their communication channel preferences for obtaining information, and identify those sources that would have the biggest impact on their own personal adopt/ reject decisions.

There was reflection on the importance of external communication channels such as mass media channels, which was discussed by Participant 246 as a way of avoiding innovation information lag within organisations: *"… webinars and 4D BIM events are up to date and cutting edge, telling you what's happening now, whereas what seems to be happening with the company … is that they seem to run behind, there is more detailed evidence out there, than what is being released internally*".

Participant 245 separately considered the variety of external mediums where information about 4D BIM could be found: "*you see* [it in] *a lot of construction magazines a lot of the online groups* [such as] *LinkedIn groups … you can find a lot of videos on YouTube",* and the role that external agency plays such as regulatory frameworks for general construction innovation diffusion:

> "*I think also as people are looking at better construction practices, less wastage, quicker time – so people are being pushed that way. I think that 'Acts of Parliament'* [sic] *and these kinds of things is also another external route that is pushing the industry kicking and screaming at times away. I think also people are becoming more aware of better practices and trying to save money and time, especially with the economy and what happened – that's been a real push and a*

shock to the construction industry to buck up their ideas. External forces not just media and television but also 'Acts of Parliament' [sic]".

Generally, participants discussed their preferences for internal communication channels because of greater trust for internal networks and mistrust of communication from external networks: "*That's the way I work. That's the way I've always done it … it is a trust thing*" (Participant 231), and: "*there's a lot of spin out there … people talk a very good game*" (Participant 41). Kale and Arditi (2010) who focussed on internal influences, and emphasised their importance within diffusion, noted that their importance is not a 'constant' and can increase or decrease over time. Participants stressed the importance of two-way information transfer within internal communication networks for multiple purposes, including:

- 'Obtaining information': "*I think it's human nature that you are more receptive and you'd rather ask daft questions of somebody you know, you are prepared to embarrass yourself a bit more easily with people you've known for years and you are prepared to ask questions that perhaps you might not in an external environment"* (Participant 189).
- 'Providing information': "*I think that's where face-to-face exchanges* [are important]*, the communication showing how it can be done*. *The things you hear from people when you show them* [demonstrating 4D] *… and that's how you realise what it is all about. You tell them and they have only heard "we don't want to be doing that – it's just more work"* [but] *it's not more work it's just getting the work done correctly in the first place … I think is a slow conversation that you have with people to help them understand where it's going*" (Participant 245).
- Or both, "*you can easily validate the information and question it - it is a bit more of a dyadic approach, where if I went externally* [for information]*, I'd only be able to obtain that information, I wouldn't be able to discuss it, and*

> *it is the ability to share, and challenge the information and try to expand upon it, which is the way that I prefer to look at it*" (Participant 210).

The work of several researchers (Emmitt, 1997; Rogers, 2003; Larsen, 2005; 2011) identify the work of Gabriel Tarde (1903) as the first to investigate innovation diffusion, who referred to adoption as 'imitation'. Rogers (2003) notes that individuals learn about an innovation by copying or imitating someone else's use of the innovation, and acknowledges that at "*the heart of the diffusion process consists of the modelling and imitation by potential adopters of their network partners who have previously adopted*". It is considered that both imitation and competition drive the adoption of innovations, and the impact of different aspects of these factors are evidenced in discussions with Participant 189 and Participant 203 who works for an early adopter organisation and discussed themes reminiscent of the 'red ocean' strategy discussed earlier.

Excerpt from interview with Participant 203:

> [I] *Over the last few years we have been a very internally focused company, so, it's kind of been embedded into us that we kind of keep ourselves to ourselves* [regarding innovation]*, which from an industry point of view, hasn't went down too well … Having said that, recently we have been getting more involved with external sources, so we've attending more road shows, taking on more external trainers and we have definitely seen the benefit of having that.*
>
> [R] That's interesting; I imagine that it was kind of a competitive advantage thing at first.
>
> [I]*Yes. It was kind of a high-level decision that we were not going to get involved with the BIM road shows and whatnot.*
>
> [R] And now that you are, do you think that is because of other people using it … and it being used wider in the market …
>
> [I] *I think that to begin with, it was because we invested so heavily before everybody else … all in the very early stages, so we kind of didn't want to share a lot of what we were taking on board at the beginning"*

Excerpt from interview with Participant 189:

> [I] *I think also there's a lot of the planners that are bit nervous about the whole 4D BIM thing and I don't know whether* [names his own company] *are further behind*

> *or further ahead even than* [competitors]*, I suspect we are not further ahead we are either average or behind, but I would say a few of them expressed their concerns that they know this thing is out there, they know that it is something that impacts upon their role and they are anxious to feel that they've got that knowledge, that they've got that information for when they need to do it. Some of them have felt that we haven't been moving fast enough and they haven't been given information necessary. That to me is like a hunger for internal information, they are asking "ok what's the company policy?", They've read about in documents and magazines and things, but they're hungry to get more "What's our company doing about it", which comes back to the internal thing really.*
>
> [R] That's interesting. Because a few years ago, the people I was talking to in industry were almost, wanting it to go away, and now it's almost the fear of the competition all the time. And the not wanting to get left behind thing, that's seems to be the driver for people.

9.3 Key actors from within the social system[i]

Explanations of the opinion leader and change agent roles were previously provided in Chapter 6. Participants were provided with brief descriptions of these, and then asked:

> ***"Can you recall any particular interaction with individuals who fit these descriptions, and how this interaction impacted upon the innovation-decision process?"***

Descriptions of opinion leaders were provided. These variously academics: "[helpful] *with the acquisition of knowledge between stages 1 and 2, between knowledge and persuasion*" (Participant 210), company principals: "*he could see the future … and is quite a persuasive person"* (Participant 245), and near-peers/colleagues: *"He is very enthusiastic about it* [4D BIM]*, I don't know where he finds the time, but he does. He's really championing the whole thing, so he came up here a couple of years ago and did a little briefing of the benefits … and he's a big believer in it and very enthusiastic about it … normally he goes away and thinks about it and always looks at ways to improve it and stuff like always asks questions, definitely the right kind of guy"*. (Participant 189)

Descriptions of change agents were also provided. These were identified variously as industry practitioners outside of the immediate network of the participant: "*they provided some evidence-based design that allowed us to really consider and persuade and challenge and ask questions of it and actually see if it was of relevance"* (Participant 210), software vendors and representatives of 'external agencies'. One of the Key BIM innovation change agents from the Government BIM Task Force was named by Participant 203: "*the best person I can describe, although he works for the government, is the guy that actually wrote the Construction Strategy from the BIM working group, Mark Bew, I've met him a couple of time, and he kind of changes my opinion every time I listen to him, about what you can and should do"*.

The researcher was also identified as a change agent by some participants (241 and 245) who had attended 4D BIM workshops facilitated by the researcher: "*You've helped* [names company principal] *understand 4D BIM and where it is going*", along with the partnering organisation that worked with the researcher in delivering these workshops, who were frequently named as a change agent by various participants:

- "*Obviously* [they are] *trying to sell products, but,* [they have] *given up time to come in our offices and do live demonstrations in the office … and answered all our questions, when some people higher up the chain were there … the right people as well, so they were able to see this and go "actually this is quite good*" (Participants 15).
- "*They are the only ones that have really, in my eyes, tried to implement it as well"* (Participant 100).
- *"They are facilitating what I think is a much easier solution in terms of linking the model to the program in terms of the BIM model"* (Participant 123).
- "*Who are trying to push the software as well, they are obviously very enthusiastic and yes, they are salesmen at the end of the day but I keep*

getting their emails: "watch this webinar, watch that webinar…" so they are a good one" (Participant 189).

One of the interview participants Participant 41 was identified as a change agent by two of the other interviewees (Participants 195 and 246), and he himself stressed the importance of opinion leaders and change agents in the diffusion of construction industry innovations, although he also stressed the importance of 'integrity' and 'trust' in any communication network.

9.4 Consequences of 4D BIM

Rogers (2003) advises that there is little research around the consequences of innovations and believed that contributions to IDT could be made through such work. Specifically, and largely to combat criticisms of 'pro-innovation bias', empirical study of three separate dimensions of consequences were called for. These were tailored for the participants in relation to 4D BIM, when participants were variously asked about:

- 'Desirable' or 'undesirable' consequences of 4D BIM
- 'Direct' or 'indirect' consequences of 4D BIM
- 'Anticipated' or 'unanticipated' consequences of 4D BIM

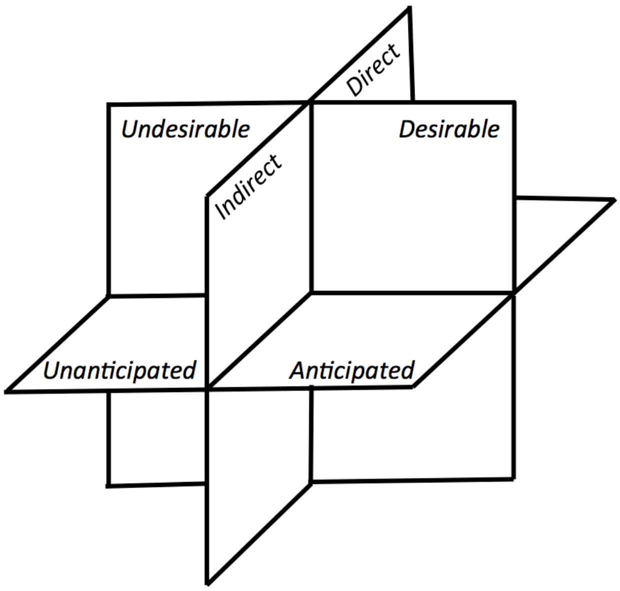

Figure 9.2: Dimensions of consequence

9.4.1 Desirable/undesirable consequences

Participants articulated 'desirable consequences' as including the greater level of detail in which you can communicate the construction plan (Participant 245), and the visualisation benefits of being able to see objects within the model being virtually constructed in alignment with the agreed construction sequence (Participant 195), which provide opportunities to make potential time savings: "*You can produce something either within the* [original agreed] *time period or* *quicker than what you have actually allocated*" (Participant 246). The benefits of modelling the virtual construction environment to ensure the feasibility of logistical and temporary works elements of the construction plan were discussed (although in these excerpts these participants refer to the overall construction 'plan' as 'the programme'): "[we] *look exactly what is happening in the site and* [in that respect] *there is very significantly high precision … I've been thinking about it in terms of validating the programme but that is, for me, a bit of surprise that it could be used to validate to programme to the extent that we are using it*. (Participant 193), and: "*to produce more robust programmes … it just helps illustrate what you're doing,* [and] *it can even help on bringing down the costs or actually highlighting costs or temporary works – how long scaffold is going to be up for etc.*" (Participant 100). Despite the additional workload involved, some participants were optimistic about the value of 4D BIM: "*Certainly a lot of coordination issues and timing issues might be resolved a lot earlier"* (Participant 123), and: *"I only see positives. I can't see any downsides, it is going to be more work and a lot more involved up front, but what it does do, is actually brings a bit of realism to the process as well*" (Participant 231) with Participant 195 identifying that: *"It improves the planning process … it will definitely make my job easier"*.

Other participants however viewed the creation of additional work as one of the 'undesirable consequences', as discussed by Participant 123: "*I think the undesirable one is that it's possibly taking longer to turn around tenders which is undesirable from our company point of view and it is possibly going to lead to an increase in resources and make us less competitive*". This was described in detail by Participant 41:

> "*I describe 4D BIM as 'a managers dream', and 'a planners' nightmare'. For the manager, he can go into the depths* [of the plan]*, all the dates and everything else … its very visual, it's very quick to watch a* [4D] *simulation of the building going up in a couple of minutes and there are huge wealth's of data contained within that animation. He can then decide whether he likes it or not and if*

something needs changing in his opinion. It's a planners' nightmare, because he's not just engaging with one manager, its rippled across different departments as well which means you get maybe 3 or 4 managers input which means that the programme is constantly getting more and more input into it … its constantly being updated … it's a constant set of moving goalposts until you manage to hit something which in theory is good enough to be a 'construction issue' [version of the plan]*. Even then, that doesn't matter, it continues to get more and more input, from more* [new] *people who enter the delivery team who might have their own ideas, so a desirable consequence is the optioneering, but the downside of it is doing all these options which we investigate - how much time do they take, how much time would be lost in that and would that time be better spent elsewhere? You get shorter programmes, but do we do it at the same risk, it's all about delivery certainty as well, and before we start trimming time off we at least want to be [in a position] where we can still deliver them on time as well. A lot of the planners' time* [is now spent] *chasing different options* [but] *are we just making additional work for ourselves? There has to be a limit to when I stop chasing gains".*

Similar discussions focussed on plan *transparency* as a one of the undesirable consequences of 4D BIM adoption. Here the benefits of improved visualisation and increased stakeholder engagement work against adopters of 4D BIM by creating additional work. The below interview excerpt with Participant 246 reveals how contractors may now have to provide increased justification for their preferred construction method, whilst dissuading clients who have witnessed alternative 4D planning output and have subsequently requested a particular method is used:

[I] *The client can have an input …* [and] *if you didn't have a model, they would just leave you [to] get on and construct it your own way.*

[R] Why would it be bad if the client has input?

[I] *Because sometimes they don't have a construction background.*

[R] So its … naivety?

[I] *Yes … on my current project* [the client] *wants it done quickest and cheapest … he has a method in his head because someone has shown him it that way, that's the way he wants it done.*

[R] And he has got stuck on that?

[I] *Yes. Because he has seen a model time-lined* [by a competitor] *showing 'this is how it could be done', and when you work it back, it's not the best way of doing it or the safest way … he's then gone 'well I've been shown it this way, why isn't this way the best way?' so that is the danger of it."*

Participants generally saw increased levels of client involvement as an undesirable consequence that generate dysfunctional conflict, however it is equally possible that these interactions will generate functional conflict which "*may be beneficial and lead to the resolution of differences*" (Emmitt and Gorse, 2003, p167). Functional conflict is useful as it can "*expose problems, reduce risks, integrate ideas, produce a range of solutions, develop understanding, evaluate alternatives and improve solutions"* (Gorse, 2003, p174).

Participants commented on similar problems of increased transparency in 4D progress reporting. Additionally, the potential difficulties of continuing to undertake a practice which is common to constructors of having a separate and simultaneous external 'contract programme' (whose progress is communicated to the client) and a reduced duration internal 'target programme' (whose progress to the contractors' construction directors) was considered as undesirable, because it would result in further duplication efforts for those producing 4D plans:

> "*If using 4D BIM at contract review, you could open yourself up quite early on to be scrutinised by the client. I have no doubt that there are a lot of companies out there, who will have, maybe a different programme that they might want to run, and they kind want to keep* [secret, and] … *not show the client as much. This … especially if you going to run one* [BIM] *model you are kind of just opening yourself up to … well basically there is nowhere to hide from the client. You are showing them exactly what you are going to be doing in the next …* ['*n* weeks'], *where you are, and what you are up to. I know you got to adopt this open and honest approach with your relationship with everybody and that's what BIM us all about, but at the same time I think there are certain aspects that need to stay internal"* (Participant 203).

Despite these concerns, the experiences of Participant 123 suggest that construction actors will continue to fulfil traditional roles regardless of the opportunities provided by 4D BIM: *"So far we have had very little interrogation of our programmes at all and anything 4D that we have done. It purely seems to be viewed as a visual tool by the client and a pretty picture"* (Participant 123).

9.4.2 Direct/indirect consequences

Regarding the 'direct consequences'**,** participants discussed the rapid diffusion of this innovation in work winning environments: "*I suppose the best thing is the 'take-up' of it and almost the fact that it is expected to be used during work winning now"* (Participant 189). Positive direct consequences also included improvements in the: "*representation of information …* [used for] *… greater and common understanding between participants and groups*" (Participant 210). 4D output can be used to better communicate the proposed construction plan across project participants, first to clients and then at operative level: "*engagement with the workforce … yes it is about programme, yes it works and is effectively almost a sales tool* [when] *used at tender* [stage], *but actually if you continue to refine it, and continue to add detail to it, you can start to produce visual method statements … and that has an impact upon accident safety ratios … as time has gone by, this has started to become a direct benefit, and we are actually targeting that use at the outset"* (Participant 41).

In addition to improvements in safety planning, on site use of 4D BIM is expected to increase on-site productivity and produce shorter task durations:

> *"With 4D BIM there isn't so much slack in the system. You're pushing people to finish. Before you would say 'it is going to take 2 weeks to do', but really, it could probably get done in 5 days. Is it about trying to increase productivity? I don't think people like trying to increase their productivity. They don't want you to know that they can do it in a shorter amount of time, or they don't want to be pushed to do it in a shorter amount of time. I anticipate people are going to be against the change, especially on the ground. But clients want it, they want the reassurance and they want to know that it is going to be delivered on time, they want the knowledge, they want to understand the risk, they want to know what is coming up, and what the issues will be. We've done as much as we can to resolve it on the computer than having to sort it out on site"* (Participant 245).

Participants also highlighted dangers with any 'artificial' programme compression: "*You are showing the client … that you can do something in a time period or a sequence,* [which] *cannot become achievable"* (Participant 246). Because of the visual benefits of 4D BIM, Participant 41 identified that, for contractors there will be more certainty of when materials will be required and less early ordering of materials, which results in uneconomical on-site material inventory. This can help improve cash flow positions and reducing storage, security and insurance costs (see Akintoye, 1995; Polat and Arditi, 2005).

If ‘direct consequences’ largely relate to the benefits of 4D BIM, the ‘indirect consequences’ relate to being able to prove the benefits to justify use. The challenges of being able to quantify such outcomes were something considered by Participant 15: *“We are not at the stage of being able to measure benefits of it. We are just on the learning curve of how to implement it. I would say that once we have completed that learning curve, then we can start measuring output data, and see if it has improved against our traditional output data. We are quite up to speed on measuring output data on how we traditionally planned buildings and until we implementing 4D regularly we won't be able to measure it and do a comparison”.*

Interestingly one participant suggested that the quality of the construction plan may be inferior to current methods as another indirect consequence:

> “*When you hand drew a programme, before you committed it to paper, you were bloody sure that it was right, as right as you could, because the consequences of having to alter it, were laborious – we used to draw them on tracing paper so you used to have to get the razor blade out and scratch away, and you would be cutting bits out and sticking them together. Whereas now, people can just quickly knock up a bar chart, print it off and issue it and not worry about if it is as accurate as it could be. Although I’m not suggesting going back to hand drawn programmes, I think that is a potential negative consequence of computerised scheduling software … that the quality of the programmes that are being produced now perhaps aren’t as good a quality as they were when you hand drew them”* (Participant 189).

9.4.3 Anticipated/unanticipated consequences

In contrast to the above, when discussing 'anticipated consequences', most participants believed that programme quality will increase because of the adoption of 4D BIM, particularly in:

- Planning and sequencing the work: "*Something that I did think would happen, and it has, is that it has highlighted quite a few* [incorrect] *things within the 'logic' that I have used on several jobs in that past. It has hopefully actually bettered my programmes and made them more logical and more workable*" (Participant 100).
- Communicating the plan to the entire team: "*The whole point of 4D BIM is* [to] *kind of paint a clearer picture of what you are actually doing"* (Participant 203).
- And resolving problems virtually before the physical build commences: "*We should be able to build the project easier, smoother, and maintain the building afterwards"* (Participant 241).

Participant 246 also identified they had previously anticipated (and subsequently verified), that the application of 4D BIM would be beneficial in identifying and resolving Health and Safety related issues in the virtual environment prior to onsite work commencing.

'Negative anticipated consequences', were that increased knowledge of building designs and project challenges provided by BIM may lead to contractors losing winnable work as: "*you have more idea of what temporary works was needed by having 4D BIM. It might help with the pricing, but also you might put too much* [money] *in and price yourself out …* [because of having] *too much information* (Participant 195). It was also anticipated that lack of commitment to adopt the innovation across the boundaries of a TPO will create problems during delivery:

"Get everyone on board to do it. I'm talking BIM rather than 4D BIM, you know get the architecture, the structural guys, services guys, everyone should be a part of it. If not everyone is not in, [then] *it is not going to work in my opinion* (Participant 241). This was a sentiment echoed by Participant 203 specifically discussing the initial learning curve of 4D BIM innovation adoption: *"like every aspect of BIM you have either got to do it or you don't … just 'trialling it' is going to be a waste of time and waste of money, and you are just going to get your fingers burnt really, you've got to be prepared to fork out the money and maybe lose a little bit of production while you are training. It could have a little bit of impact on the planners' progress for a bit until he gets up-skilled and changes his way of work".*

In discussing 'unanticipated consequences' Participant 210 returned to the theme of the potential of sequence optimisation through team planning, and how it could be realised if participants are able to provide constructive feedback and input rather than acting as passive recipients of information: "*it has highlighted the culture I suppose, it has highlighted the way we approach things … general working practices, without being able to observe 4D BIM, I suppose I wouldn't have identified this lack of feedback … so it has allowed us to understand the problems that little bit better*" (Participant 210).

Participant 41 described how the adoption of 4D BIM and its subsequent reinvention as a tool for progress monitoring led to unanticipated 'radical' process changes within their organisation. The process was described as:

1. Deciding that the material quantities as derived from the model would be used as the basis for measuring progress.
2. Adjusting how they structure and use the CDE to share these quantities with appointed subcontractors.

3. Deciding that the work can only be recorded as being 100% complete, when inspected by the main contractor using approved QA processes
4. Only appointing subcontractors who agree and comply with these processes.
5. Only using these firms on their ‘approved subcontractor’ and ‘invitation to tender’ (ITT) decisions.
6. Amending the wording of standard sub-contracts in accordance with these decisions.

Whilst 4D BIM adoption had been anticipated, the actual rate had been unanticipated by Participant 189:

> “*I think it was an anticipated consequence* [diffusion]*, but I didn’t anticipate to that degree, maybe that’s a good thing, because it shows … that it has becoming an important part of the work winning side of things … we are just about to tender for* [names project]*, a £40 million pound project and they have already said that BIM will play a huge role in that and part of the pre-qualification questionnaire … you had to demonstrate your BIM knowledge and BIM experience, and that's becoming more frequent now on the PQQ side, it means we just have to get up to speed and give them more and more examples of where we have done it … There is definitely a demand there from the work winning side of things and we are having to move forward to delivery that”*.

Whilst this response highlights the importance that market demand plays in diffusion, Participant 246 identifies the criticality of the ‘exposure’ of an individual decision-making unit to the innovation, (the first stage in the amended innovation decision process presented earlier): “*What converted me? The fact that I have seen that many different uses of it … I was a cynic, it was a new technology that just looked like it another product being waved in your face …* [providing just] *a nice picture, whereas now I’ve seen the engineering use of it. You can construct … a building before its even been built. We have come so far, but the next step is a construction wide roll out. It needs to be embraced … You still have the cynics who don't want to embrace it because they are afraid of change”* (Participant 246).

9.5 Time Predictability

The final question related to the problem of construction industry project time predictability and perceptions about the potential impact of 4D BIM. The following text was read aloud [4]:

> *The government has a target for 2025 that all construction projects are to be delivered 50% faster (from inception to completion) than the industry 2013 performance, when only 45% of projects were delivered on time or better.*

The participants were then asked:

> ***"Do you think the use of 4D BIM can help improve the time predictability of construction projects (and if so how)?"***

The majority opinion was that some level of improvement to construction project time predictability can be achieved with the use of 4D BIM, articulated by Participant 245:

> *"4D allows you to be more accurate in your estimations, planning wise, it's better visually, people clearly understand it and grab the concepts and actually see what need to be done first rather than trying to work through a Gantt chart… that can only be a good thing and it has to* [happen] *in order to get that 50% improvement … It can be done – I mean it's only as good as the people inputting the data and planning but if the planning is right and everybody is talking … Planning is key and I think communication from planning to all the other teams as well as their response to us is also key. Yes, I think it can do"*.

However, for this increased level of accuracy to be realised, Participant 15 argued for the need for more reliable information to be available for the planning of construction activities and task durations. He identified that this could be achieved through the capture of actual performance data and the re-use of this information in order to be able to determine future task durations: "*being able to feed output data back into the cloud would be a big help because at the moment it`s all manual recording … but been able to record your actual progress and then just feed* [this] *back in some sort of cloud and then download that data to your*

4 This statement had also been provided to the participants within the question list (see Appendix D-4).

next program, that should give you greater certainty in your durations" (Participant 15).

Participants usually considered that predictability improvements could be gained by also altering other aspects of the project delivery process, such as increasing off-site periods in order to get reduced on site periods: "*the time on site, I would say yes, the time overall from inception, I would say no. I think, maybe the time they spend producing models in the first place and the information within the BIM models, maybe the fact that they might spend longer on that will ultimately help with the time on site*" (Participant 100). Optimising of project tendering and procurement practices to enable earlier involvement by constructors was also considered against this question: "*Yes, I do, but I wouldn't say just for the construction phase … we are focusing too much on visually representing the construction phase … [but] … we are not using 4D BIM in the design phase, if we were able to visualise* [the construction process] *during the design process, and look at the intricacies of that, we would be able to improve, understand and optimise potentially from 'strategic definition' stage, however that is hindered by your typical procurement [arrangements] in terms of sequencing appointments, so whether we appoint the contractor, you know, the proper people at the right time* (Participant 210).

The use of 4D BIM innovation in conjunction with use of other construction innovations such as pre-fabrication and modern methods of construction was considered as a more pragmatic improving construction project time predictability: *"I think it can help improve time predictability, but I'm not sure it can do it to the point where projects will be delivered 50% faster, certainly not on its own. I think the only way you going to get it that much faster is if you massively increase offsite construction*" (Participant 15), however, there were differing opinions over how the benefits of prefabrication could be used for each project: "*I think the only other ways to improve time, would be more pre-fabricated solutions almost 'off the shelf' solutions but it's not that kind of industry, almost a lot, I know all of the elements are similar but the look of the buildings always quite unique"* (Participant 100). Participant 41, who has extensive use of 4D BIM believed that his current project where 4D BIM is being used in conjunction with MMC whilst maximising the advantages of virtual prototyping would achieve the desired result: *Yes, I actually think the target is achievable … I believe an improvement of 50% faster is possible, certainly. From my experience with 4D in the last 5 or 6 years I definitely think its achievable, I think you may see it going even higher than that* (Participant 41).

Participant 189 believed that although 4D BIM innovation may eventually produce gains in time predictability, good application of trusted practices remains a key issue in trying to achieve this target:

> *"I think it has potential to in the long term.* [But], *I should say, in the short term I'm a bit sceptical. There is a lot of different initiatives that we've tried on sites before and not necessarily as high tech as 4D BIM to try to improve time performance and some things have been beneficial and some things haven't. The fundamentals of having an accurate programme, having a procurement schedule that you monitor it weekly, at least, and you flag up issues before they get too bad. I don't think that is ever going to change. If the innovation of BIM improves that process, then yes it has a part to play and I think it will, but in a short term, I think until we go through that learning curve it's like anything else, I don't think the benefits will come until later".*

Several concerns were noted by the participants including difficulties of innovation diffusion across organisational boundaries within TPO's, which may hinder opportunities for the application of 4D BIM to help with time predictability improvements: "*It's no good just the planner using the software, it has to be a team approach … I think if everybody produces the correct level of information at the correct time, and we can use the 4D BIM to showcase and highlight that,* *then, yes I do think that it could help improve the predictability of construction projects*" (Participant 203).

The uncertainties associated with site conditions and project unknowns were also reflected upon: *"It can help improve the cycle of the construction project from conception to actual usability. Whether it can help with predicting the construction time itself is very dubious because of the unknowns. The problem is we build this perfect model on a site that looks brilliant on screen but in reality, is two completely different things"* (Participant 246).

The quality of project decisions and decision makers was also identified as a key factor affecting the time predictability of the construction industry, highlighted in the below excerpt from the interview with Participant 193:

> [I] *If something can be done to make a project faster it should come from key decisions and key decision makers. Does that make sense? With a normal programme, the problem is the decisions are so poor, and to put it very bluntly that itself hampers the programme, it makes it so much more expensive, it stretches the programme … it all comes to decision-making rather than anything else, and it if those 'right decisions' are not made by the people in charge then nobody can help them, so no matter what they do, they use BIM, they use 4D they use '6D', whatever, nothing is going to change as long as they don't have good decision makers.*
>
> [R] That makes sense, it is wider than…
>
> [I] *Yes, it is much wider, it happens at a much higher level. Because I don't want to* [just] *quote* [answer with] *'projects or people' that's why I'm like keeping, slightly off that question you know, that why I am giving a specific example of how projects are dragged and public money is wasted is for so many years.*
>
> [R] Well let's just explore that a bit, is it the quality of the decisions that are poor or is it the quality of the decision makers that are poor?
>
> [I] *There are too many reasons. For example, people just don't want to take any chances.*
>
> [R] *Risk adverse?*
>
> [I] *Yes, either they sort of delay the decision or they keep it aside or push it for someone else to take at a later point, those sorts of things and then the whole programme is delayed, or kept on the 'hook' because the decision is never made.*
>
> R: Yes

> [I] *And you know, somebody has to give the word and make a decision and put the money aside, task people to do this job and get the job done it can be a simple as that and it just doesn't happen and it is so frustrating".*

Poor construction project time predictability was discussed as being a result of committing to unrealistic durations to win projects: "*Definitely yes, because the programme is realistic. We are used to working with unrealistic programs sometimes, because we haven't use BIM to create the programme it is just people putting their finger in the air for certain items* (Participant 241). Issues of 'optimism bias', were also discussed, specifically that 'unrealistic' tender programme durations can ever be achieved by the delivery team:

> "*the 50-week programme is always the stock answer that the client wants to hear, whereas the real … if you actually do this and look at the sequence, you will get an answer that's probably different to that. Everyone might stop kidding themselves, because people do kid themselves with programmes and sign up to it and we are the worst for it, well contractors are the worst offenders. It will help predictability for the very reason that I just outlined, if you end up with a realistic programme of course it will be delivered on time … the certainty of delivery becomes a lot more achievable"* (Participant 231).

9.6 Summary of Semi-Structured Interviews

In summary, there are several key points which have been identified through analysis of the qualitative data in chapters 8 and 9, which can be considered alongside the results of the study so far:

- System complexity, industry characteristics and organisational culture and practices are considered to contribute to the perceived low rate of innovation in construction.
- The importance of the top-down innovation pressure as well as bottom-up problem solving are considered as being equally important for construction organisation innovation adoptions.
- Despite some of the benefits in visualisation and design coordination that have been realised using BIM, the actual quality of production information was not believed to have improved, and equally, its use has presented several challenges in terms of increasing levels of options analysis, and its potential for magnifying any problems of incomplete information.
- 4D BIM use was often linked to levels of client demand or project scale, although there were clear examples of how such use had added value to construction planning.
- Each stage of the innovation-decision process about 4D BIM was considered. It is considered that a new model of the innovation-decision process, specific to modular technological process-based innovations is required.
- Research participants expressed preferences for internal communication channels because they trust these internal networks, and somewhat, mistrust of communication messages from external networks.
- The principal consequences of 4D BIM innovation adoption are: the opportunities afforded by the facilitation of feedback loops to further reduce transactional distance within plan communication; the associated

potential increases in planning effort needed because of additional interactions needed with construction team or client team members; the increases in the quality and validity of the plan produced; and an obvious client demand for this planning output experienced in front end work winning situations.

- Some level of improvement to construction project time predictability can be achieved with the use of 4D BIM.

Several of these points will be returned to in the final chapters. Chapter 10 presents a new model of the innovation-decision process, and Chapter 11 concludes the work by considering the key findings from all stages in this study.

Chapter Endnotes

[i] One prominent method to investigate the structure of the social system in which innovation diffusion occurs, is with Social Network Analysis (SNA). In this method networks are graphically constructed and visualised with 'sociograms' using nodes to represent actors and lines to represent relationships. SNA was successfully used by Larsen (2011) in case study research to map the innovation relationships of individuals bounded within an organisation. Use of SNA by Larsen showed how individuals become aware of an innovation and how their opinion is influenced during the early stages of the process. In the present research project, the quantitative data collection methods of either of the larger scale questionnaires were not designed to collect responses appropriate for SNA methods which require actors to name (or identify anonymously) individuals within their network that they communicate with in relation to innovations.

Chapter 10: A New Model of The Innovation-Decision Process

10.1 What is a model?

Models help us understand aspects of the complexity of the world by providing a simplified, or 'idealized' representation of some phenomenon, or system at work. They are 'abstractions', that contain assumptions about the relevant, decomposed, elements of a system or real-world situation, and as such, are used for purposes such as, generating visualisations or simulations, drawing inferences, making predictions, or for problem solving. *"The purpose of the model is not to describe reality but to reduce it to a more manageable form, losing many of the minutiae of reality, but, hopefully, retaining the general form in a way which is more easily understood"* (Raftery, 1998). People from all walks of life use these in everyday situations, although they tend not to be thought of as 'models', with examples including maps, paintings, photographs, diagrams, toys, video games and other computer-generated simulations. Models are used extensively across most academic disciplines (and sub-disciplines) including the arts, humanities, and the social, natural, formal, and applied, sciences. Within the social sciences, conceptual models[1], are commonly used for sense-making purposes, to facilitate better understanding, and to convey meaning. Raftery (1998, pp.299–300), also suggests that models are "*useful only as long as they appear to fit their situation, to describe or analyse a problem adequately. They are useful until they are disproved*". Where some models fail at points and require complete revision, others merely require refinement or enhancement so that they continue to exhibit likeness to the phenomena being represented.

1 Other types of models include Iconic (scale) models; Analogue models; Symbolic or Mathematical models; Operational models, and Graphic Models. Raftery (1998) lists some of these, in an excellent account of what models are.

10.2 A new model of the innovation-decision process

Analysis of the data from this study, suggests that for the construction sector, several enhancements to Rogers (2003) model of the 'innovation-decision process' can, and should, be made. This new model is of use when considering the diffusion of innovations such as 4D BIM, which are *modular technological process-based innovations* being introduced into a multi-level complex system[2]. The innovation decision process for these innovation types does follows a similar, albeit amended, process to the model that is central to IDT. Although Rogers' model is largely accepted as being generalizable across organisational-, marketing-, product-, or process-based innovation-decisions (Windahl, Signitzer and Olson, 2008), it has also faced criticisms within the construction management research community. Several researchers (Emmitt, 1997; Widén and Hansson, 2007; Shibeika and Harty, 2015; Lindgren and Emmitt, 2017) point out that because of the peculiarities of the sector - it being project-based, structurally complex, risk averse, suffering from 'short-termism', and bounded by uncertainty (Winch, 1998; Barrett and Sexton, 2006; Loosemore and Richard, 2015) – for it to be applicable within construction, Rogers' model requires theoretical extension. Larsen (2005b) stresses how it is "*a practical yet almost over generic theory with inadequate consideration of context*".

In this new model, diffusion now consists of 6 more involved stages. Each of these stages (and the components with them), will now be described. The enhancements to the existing model will also be verified and supported through the findings arising from this research project[3]. The amendments to the classic model are shown as black text boxes with white/grey text in Figure 10.1.

2 And in this case, as part of the diffusion of the more disruptive radical BIM-innovation.

3 Where 4D BIM will be referred to, even though the main purpose of this section is to describe a new generalizable/transferable model.

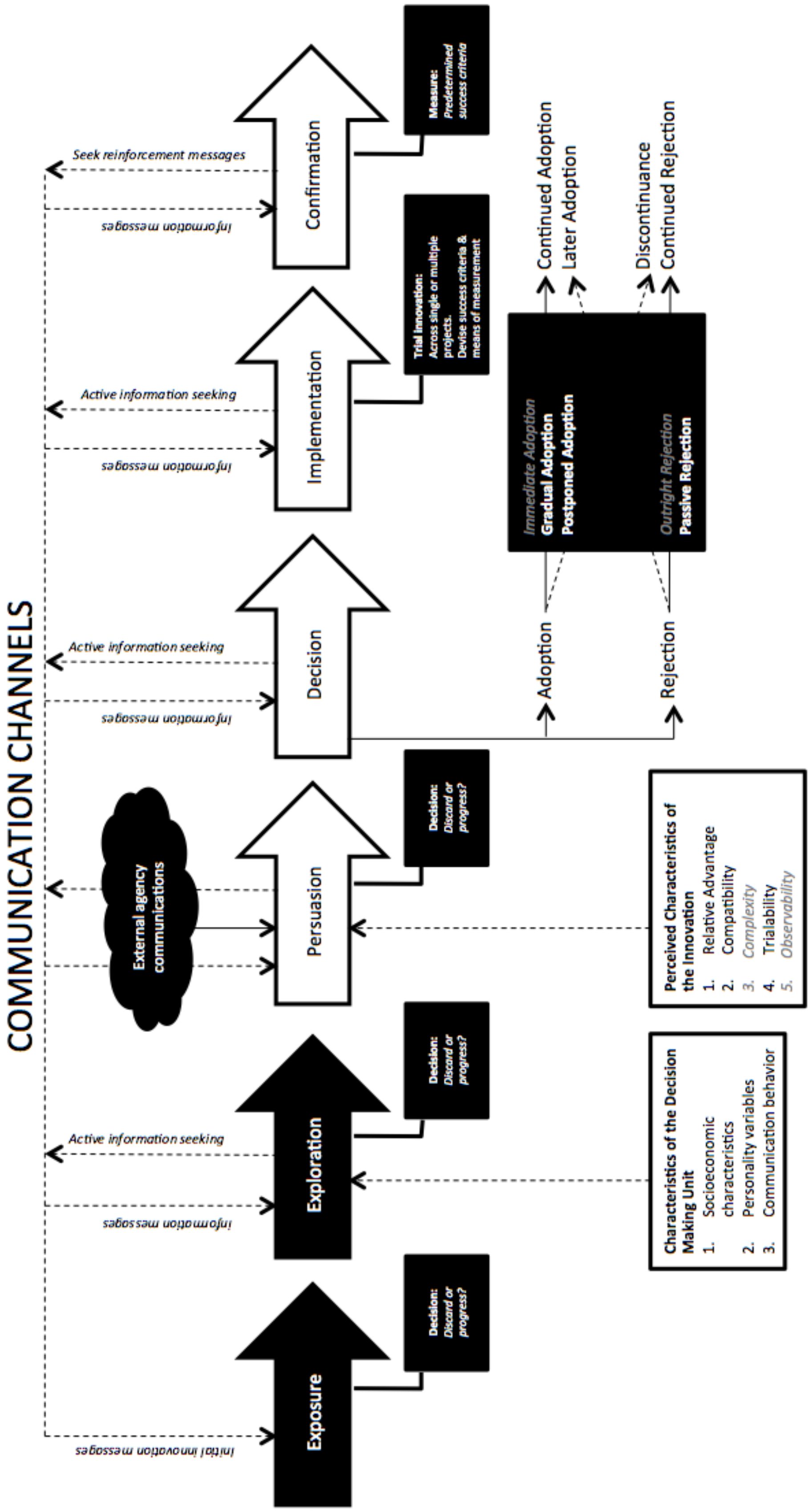

Figure 10.1: New model of the innovation-decision process as applicable to modular technological process based innovations

10.2.1 Exposure

Rogers (2003) initial 'knowledge' stage has necessarily split into two closely related, but distinct, stages. At the outset of the innovation-decision process, decision-making units are stationed on the threshold of the (I) *exposure* stage, where they remain as passive recipients of information, until exposed to an innovation through various communication channels. The actions of 'opinion leaders' as promoters or gatekeepers of the innovation remain important, and at this stage such one-way 'initial innovation messages' can either be 'discarded' (or ignored) or 'investigated' further. Such thinking, about the behaviour of decision-making units at the outset of the process, is opposed to Larsen's belief (2011, p990) which is that actors are not 'passive' at the commencing stages, however the semi-structured interviews undertaken during the explanatory stage of the project, revealed that the participants (i.e. decision-making units) became first aware of 4D BIM through chance, and exhibited passive, rather than active behaviours. Their responses suggest that this first stage of the innovation decision process, 'exposure' actually occurs because of some receptivity to the actions of opinion leaders or change agents, commonly through messages transmitted during routine attendance at work (company briefings) or at an educational establishment. The data revealed how exposure also occurs through participation at professional events, or engagement in their own personal communication networks. Notably, it also occurs increasingly, through media 'consumption'. It is worth commenting that the scope and influence of modern media on innovation diffusion within the construction sector, and across general society, has expanded enormously since Rogers' first (1962) and then last (2003) editions of 'The Diffusion of Innovations' were published. Hence, actors can now be inundated with the 'initial innovation messages' shown in the new model, but not just through traditional print media, or radio or television broadcasts. Now exposure also occurs through general web-based browsing (text- or video-based), or through attending 'webinars', and participating in online groups. For example, Participant 100 described their initial exposure to 4D BIM, by: "*Seeing it on, YouTube clips and things like that, and in [the] press it was starting to get talked about in magazines*", or how Participant 246 discussed how in terms of innovation (and in contrast to getting information from their organisation), modern media was described as *'*up to date*'* and *'*cutting edge'*, "telling you what's happening now"* (Participant 246)[4].

10.2.2 Exploration

> *"My first knowledge of 4D BIM came through university, and then obviously through my university studies I learnt what 4D BIM was and it interested me so I pursued it a bit on my own … a lot of my first knowledge was just getting through studies and self-interest, rather than being introduced to it by the company"* Participant 15).

The data from this research reveals that, like Participant 15, it is only after 'exposure' that a decision-making unit continues on through the innovation-decision process. Here they enter (II) *exploration* stage, where depending upon their characteristics and perceived needs, they will begin to demonstrate more active information-seeking behaviour about an innovation. The decision-making unit starts the process of formulating a decision and again may choose to discard messages about the innovation, or they may progress onto the next stage. Here, this model also differs from Rogers original model by recognising that after the initial exposure stage, communication channels then involve 2 way acts of communication with *active information seeking* being performed by the decision-making unit to supplement the innovation information messages received. At each subsequent stage the decision-making unit continues to seek these 'information messages' shown in the new model, to progress through the

4 Silver (2012) discusses the exponential growth (and variable quality), of available information since the early days of the world wide web, and notes an IBM estimate quantifying how over 2.5 quintillion bytes of data are now generated each day.

decision-making process but they may discard the innovation-decision process at any stage if they experience ‘discordance’ during deliberation. Hence, as also shown in the model, the communication behaviours of a ‘decision-making unit affect’ become particularly important from this stage onwards.

In this project, although no statistical significance was found in tests of association between communication channel preferences and adoption levels of 4D BIM, in the semi-structured interviews, participants expressed definite preferences for their internal communication channels for aspects of ‘exploration’ because of issues of ‘integrity’, ‘trust’, and the importance of two-way communication. Participant 189 called it ‘human nature’ and argued that: “*… you are more receptive and you’d rather ask ‘daft’ questions …* [and] … *are prepared to embarrass yourself a bit more easily with people you’ve known for years …* [and] *perhaps you might not in an external environment*”, where Participant 210 identified that, ‘innovation information’ being explored for using internal communication networks could be ‘discussed’ and ‘challenged’, rather than merely being ‘obtained’ through external networks.

From this point, the remaining stages in the new innovation-decision process model remain as per Rogers’ original model, with the remaining enhancements being an additional ‘environmental factor’ (of *external agency communications*), and several additional ‘decision-action points’ and ‘outcomes’. Again, these are all shown as black text boxes with white text on Figure 10.1., and are now discussed.

10.2.3 Persuasion

This stage occurs when an impression or attitude is created about the innovation. With *modular technological process-based innovations* such as 4D BIM this research has confirmed that although the perceived characteristics of ‘relative advantage’, ‘compatibility’, ‘complexity’, ‘trialability’ and ‘observability’ of an innovation do play a role at the persuasion stage[5], trialability’ (the opportunity to experiment with, and use the innovation without commitment), and ‘compatibility’ (between the innovation, and existing infrastructure), and for this particular innovation, certain ‘relative advantages’ (i.e. in plan communication) are more significant than aspects of ‘complexity’ and ‘observability’ (In this study, the inferential tests performed for ‘trialability’ and ‘compatibility’ in section 7.11, yielded Fisher’s Exact Test Statistics of .005, and .026 respectively).

The data reveals how, ‘persuasion’ also occurs because of reasons other than the perceived characteristics of the innovation. At this stage of the process the effects of direct communication from relevant external agents upon the innovation-decision environment, are also felt most strongly, as these may also persuade an adoption/rejection decision to be made. Hence, *external agency communications* are provided as a further model enhancement. Key innovation information messages from government or other notable actors across the wider construction marketplace offer examples of such external agency communication. Some examples are now detailed in turn:

Within the UK Construction Industry, the UK Government provides perhaps the best example of such an ‘external agent’ by combining policy, regulation and championing behaviours (and its importance to innovation is recognized

5 Refer variously to Chapters 6, 7 and 9 for the introduction to, and extensive discussion of, these characteristics in relation to 4D BIM.

throughout the literature, e.g. Gann and Salter, 2000; Aouad, Ozorhon and Abbott, 2010; Caerteling *et al.*, 2013; Na Lim, 2014). The role of Government within the 'persuasion stage' of the innovation-decision process was summarized by Participant 210: "*if you look at it in macro level - top down, I would say it* [Government] *provides the focus, it provides an aim for people in terms of where to get to, you know, gamification of the project environment, gamification of the industry … government strategy provides the aim".*

Another example of how external agency communications affect 'persuasion' comes from marketplace interactions. The data reveals how concerns by decision-making units over if, and how, their competitors are adopting innovation can influence attitudes and initiate subsequent 'imitative' innovation behaviour. Such fears usually revolved around how their host organisation is performing, relative to their competitors (i.e. if they are falling behind, or being expected to be using it)[6]. This is evidenced by Participant 189, when reflecting upon a notable experience that occurred whilst attending 'post –tender interviews':

> *"… we took a 3D model along, which we developed to show the site logistics and sequence, basically to demonstrate that we understood the works, we understood the problems and tried to find solutions. We thought it would go down very well, but the feedback was that the other three tenderers had something very similar. So, if you went to that interview and you didn't have something like that, you would look inferior at first perception even if your ideas were good. It was almost as if it was being expected of you".*

6 Whilst such concerns may apply to the 2nd- or late- 'movers', some of those organisations who could be considered 'innovators' or 'early adopters' (i.e. 'first movers'), were found to also have their own concerns around trying to actively restricting innovation communication and marketplace interactions. These organisations have positioned themselves to offer 'differentiation' to clients through a unique selling proposition (USP) that provides business benefits derived from innovate behaviours appear to act differently, and, for this reason, the data suggests that such organisations become much more internally focused to retain that competitive advantage.

10.2.4 Decision

The fourth stage, 'decision*',* occurs when a decision-making unit elects to adopt or reject the innovation. In this model although the multiple implications of choice identified by Rogers (2003) remain (i.e. that an initial decision to adopt can be followed by 'continuous adoption' or later 'discontinuance' of the use of the innovation. And, conversely an initial decision to reject an innovation can be followed by 'continuous rejection' or conversely by 'later adoption') it is more likely that for *modular technological process-based innovations* one of five more nuanced 'outcome types' will occur. These include the typical outcomes of *gradual-adoption, postponed-adoption,* or *passive-rejection*, and the rarer outcomes of *immediate-adoption* or *outright-rejection*. Hence, due to the project-based nature of construction, the outcome of any 'adoption' decision made is usually a 'postponed-adoption' decision or a 'gradual-adoption' decision. This is because decisions over if, and (the timing of) when, any adoption decisions are made, are largely in relation to the timing and requirements of individual projects. The results of this study reinforce this by showing that for 4D BIM, that the usual time lag recorded between first awareness and actual adoption was between 2.38–3.00 years (28.5–36.0 months). This data supports the model that innovation adoptions are either 'gradual' or 'postponed' but rarely 'immediate'[7].

'Postponed-adoption' is a concept introduced by Emmitt (1997) and for modular technological process-based innovations, this could be the need to wait for the commencement of the next immediate project, or to target a more suitable future before adopting the innovation. This was evident throughout the semi-structured interviews, as described variously by Participant 189, "*you maybe come across a project where you think 'oh, this* [innovation] *might work for that', but it is very ad-*

7 Of the 61 respondents (from a total of 97) that confirmed 4D BIM use/awareness of use from someone in their organisation, only 6 of these (9.8%) adopted and used 4D BIM 'immediately', that is, within the same year of recorded first awareness.

hoc", and then by Participant 123, "*it's just trying to find the right opportunities to bring* [the innovations] *to use*. [A project] *might come in tomorrow but it might not be for 2 years, where I can actually see a use for* [it]".[8] Alternatively, 'gradual-adoption' of the innovation occurs. 'Gradual-adoption', is a new concept generated in this work that involves trialling the innovation[9] in selected project instances before rolling out the innovation further, often as part of an extended trialling process. In this outcome type, trials are conducted without obligation or commitment to fully adopt the innovation, yet organic organisational adoption ultimately occurs and the innovation subsequently becomes part of accepted practice. To reinforce this, attention is drawn back to interview content from Participant 41 who gives an example of how gradual adoption occurs, and is constrained by low industry profit levels, and organisational attitude toward risk:

> *"We tend to want to trial them [innovations] on one project … we get this long cycle where we develop an innovation, we trial it somewhere and that project is probably going to be between 12-24 months, and only at the end of that do you gain the learning and then they are probably going to want to trial it on 4 or 5 [other] projects simultaneously. You get to the end of those and then it may get rolled out across the business, so you are looking at anywhere between 2-4 years to deliver an innovation across the whole workplace. The reason that that scenario ends up happening, is that profit margins are quite low in terms of percentage profit, and we are a very risk adverse industry based upon that, and those two things combined with the long lifecycle means that innovation is … it's not stifled but it is extremely hard to drive through, and because we've never done dramatic change its very much tiny incremental steps because of the risk involved it does tend to slow the effect and that's an industry wide thing".*

If conversely, the decision is to reject the innovation, or to 'do nothing' then the outcome of 'passive-rejection' most typically occurs. Rarer outcome types include 'immediate-adoption', and 'outright rejection*',* although these are infrequent with technological process-based innovations. To reinforce how rare 'outright rejection' is, attention is drawn to the results from the explanatory questionnaire

8 Several participants also considered how the 'innovation source', impacts upon the timing of when an innovation is adopted, such as Participant 123: "*its subcontractors and suppliers that are bringing these new 'products' to the market, so it's trying to find the right project to get them implemented on*".

9 And with a Fisher's Exact Test Statistics of .005, the significance of being able to trial innovations within the sector has already been established, and discussed earlier, within this work.

survey, where it was asked '*Please confirm if a decision has been made to adopt or reject the use of 4D BIM for the planning of construction work*'. Of the three response options offered: 'adopt', 'reject' and 'undecided/no decision made'. Only 1% (n = 1) of respondents, confirmed that a definite 'reject' decision had been made. In contrast, 67% (n = 65) confirmed that an adopt decision had been made[10], but the remaining 32% (n = 31) of respondents advised that they were undecided, and that no decision had been made. Hence, regarding innovation diffusion, it can be determined that 'passive rejection' i.e. making 'no (definitive adopt/reject) decision', occurs more frequently than an 'outright rejection decision'. It is also true that when a 'passive rejection' outcome occurs, this may be followed by later outcomes of either gradual-, or postponed-, adoption.

In addition to decision outcome types, this study also reveals another factor of organisational size which affects the 'firmness' of the actual decisions made within the 'decision' stage of the innovation-decision process. It was revealed from the explanatory questionnaire survey (in section 7.10), that the most frequent type of adoption-decisions made were 'authority decisions' (those made by organisational upper management), followed by 'collective decisions' (those made by consensus), with the least frequent option being 'optional decisions'. Bivariate analysis then demonstrated associations between company size and the types of organisational decisions made[11], revealing that innovation adoption decisions in larger companies (250 persons+) are much more likely to require 'authority-decisions' to be made. Within this study, and for the particular innovation of 4D BIM it was also established that, there is more likely to be

10 Although the 2nd questionnaire survey was designed to be able to assess the difference between the timing of first awareness and first use (recorded in years), which directly relate to the 'exposure' and 'decision' stages, and can assist in identifying 'immediate-adoption decisions', It was not designed to be able to truly differentiate between gradual-, and postponed-, adoption decision outcomes.

11 Producing a Fishers Exact test statistic of .019

personal use of 4D BIM within larger companies[12]. One inference that can be drawn here is that a definite 'authority-decision' communicated within an organization, much more likely leads to (quicker) personal adoption and use of the innovation by individual staff members[13]. These definite 'authority-decisions' made within larger companies was referred to by various participants working for such companies, several of whom, also implied outcome types of gradual-, or postponed-, adoption:

- "*They definitely said yes we are going to adopt it*" (Participant 203).
- "*The initial decision was to adopt it. It wasn't ever rejected*" (Participant 41)
- "*Definitely the corporate decision was to adopt … to commit the resources and the time necessary, because of the recognition that it is something we need to do to remain competitive. It is very much early days but it has been a corporate decision to move in that direction really*" (Participant 189).
- *"The decision was made that it was useful and that we would develop it further*" (Participant 123).

In contrast, the data also showed how smaller and medium sized decisions can be more flexible to offer 'immediate-adoption' decisions: "*After* [names company principal] *first use of it … it was an initial adoption [decision]. For him it was quite clear because he ran the company, it's a small company, it's something* [a decision] *that you can make quite quickly*" (Participant 245). However, the data also show how such decisions can also be less 'firm', producing 'passive-rejection' outcome types, and indeed slowing levels of individual adoption and

12 Fishers Exact test statistic of .001

13 Although as found from the results of the case study detailed in Chapter 4, even where such definite 'authority decisions' are made by large organisations, variances exist between individuals in terms of adoption and use.

use: "*It definitely wasn't a rejection, but it was very, it was almost an arm's length thing, they kind of just let me get on with it, they paid for the software and the course with ASTA and it was just the 'oh yes, that seems like a good idea' but it was very early days for me so I'm still learning and so it wasn't reject outright, but it also wasn't adopted by the group, it was just, something where they said "yeah, ok, you go away* [and do it]*"*" (Participant 100).

10.2.4 Implementation

If the decision is to adopt, then this will be followed by the fifth stage 'implementation' which is when the process of the innovation being used, begins either through full adoption, or by trial. Rogers (2003) confirms that this process continues until the innovation is 'institutionalised', and is no longer considered as being new and distinct from regular business operations. Success at the 'implementation' stage is subject to much uncertainty, not least within organisations because often, the persons who have made the previous decision to implement, are often different from the actual implementers themselves. It is important to note that although this study found that organisational attributes are more important that individual attributes, the implementers themselves should not be considered to be mere passive 'acceptors' of innovation-decisions. Whilst there may be enthusiastic adopters, equally there may be those that resent being directed to adopt an innovation, and seek to challenge or discredit it.

Generally, the results of this study of 4D BIM, provide numerous examples of enthusiastic adopters showing appreciation for the benefits of, and consequences from, this particular innovation. However, the exploratory case study, undertaken during the 'implementation stage' of a process following an 'authority-decision' (that all future company projects would use BIM), along with the final round of interviews revealed several fears and concerns of organisational staff. Specifically, that in terms of innovation implementation: there are 'people issues' in terms of individual ability to use, and commitment toward, such innovation[14]; that productivity reduces during necessary 'learning curves'[15] (and this may not be recognised, or understood by management); and that use of such innovations creates additional work (and additional resource may not be forthcoming)[16]. Additionally, further analysis revealed how such innovation implementation can also lead to inefficient effort duplication[17].

Such concerns reinforce why the 'trialability' of innovations is considered important, hence this new model also shows the explicit 'action point': *Trial Innovation*. In the project-based construction sector these trials occur on an individual project, or a series, of projects. For such trials to be considered a success they should be subjected to post-project reviews, where results, determined by measurable success criteria that is established at the outset of the innovation implementation, are analysed to determine if ongoing adoption will continue. Participant 41 gives an account of this, describing his (prior to employment at a large construction contractor) experiences as a 'change agent' working for a software vendor promoting 4D BIM innovation:

> "[Vendors] *spend a lot of time building up and giving an impression of the provable benefits, and the construction industry tends to take them very much with a pinch of salt, and wants to try them themselves. The best way I found across both ways is, you end up trialling on a single pilot project but setting very clear goals of 'this is what success/ failure looks like' and you have to score it, but it has to be very criteria driven … For me* [the answer is] *its - trial it, but if it meets the measured criteria then it works, there is no need for that middle second phase of 'well let's trial it across 5-10 projects now'. One of the last experiences that I had with* [Software Vendor] *was we went from doing a couple of very small pilots in isolation to then doing a sort of … they called it an extended pilot* [but] *it*

14 "*It's just culture, you need people who want to try and learn something different, with the correct attitude*, [and who understand the] *possible benefits … It's just about changing people's attitudes*" (Participant 3).

15 "*You've got this learning curve they go through before they become proficient at it and we all start seeing the benefits*" (Participant 183).

16 "*It is incredibly resource intensive to develop and then maintain a 4D model*" (Participant 208); "*4D is great, but it requires intense effort to create and update which makes it a proposition of: 'Is it worth the effort to create and maintain?"* (Participant 163)'

17 Refer to Figure 4.3 for an example of this, which relates to the hybrid project delivery processes employed when adopting BIM innovation.

> *became the beginnings of a mass roll out, although it was structured in such a way if that had failed, as part of the larger pilot the roll out would have stopped at the 10 projects. The minute it crossed the 10-project threshold it became 'this is the way we are doing it, the way it is going to happen from this day forth'. In reality if you trace it back it was because of this 1 pilot project that had been successful".*

It is also expected that at this stage some degree of innovation 're-invention' may also occur by which an innovation or its use may be modified or altered to suit the needs of the various adopters. The results in this study have implied that 4D BIM was being successfully 're-invented' by several construction project practitioners for their own purposes: "*it is not just used by the planners. It is also used by the construction managers, and it is used by the commercial guys, it is used by everyone … It is used by different people for different purposes*" (Participant 193). Rogers (2003) advises that such innovation reinvention leads to both a 'faster rate', and 'higher sustainability' of an innovation.

10.2.6 Confirmation

The final stage of this model, 'confirmation*'* occurs when a decision-making unit tries to obtain 'reinforcement' regarding the decision made, although it is possible that seeking such reinforcement may lead to a subsequent rejection of the innovation in light of new information. This new model shows two additions at this stage. The first addition explicitly acknowledges that at this stage these 'reinforcement messages' are sought by the decision-making unit to supplement any innovation information messages received. The second addition is the 'action point' of *Measure*, which refers to the measurement of data identified as relevant to the 'success criteria'. This, along with the means of measurement, should be devised at the outset of the implementation stage. The importance of undertaking such measurement during trialling was also confirmed within this study[18]. Unfortunately, at the time of the study, because of issues associated with project duration, few if any, organisations seemed to have moved fully beyond the implementation stage, and into the confirmation stage, although some had begun to consider the means of such measurement: *"We are not at the stage of being able to measure benefits of it. We are just on the learning curve of how to implement it. I would say that once we have completed that learning curve, then we can start measuring output data, and see if it has improved against our traditional output data. We are quite up to speed on measuring output data on how we traditionally planned buildings and until we* [are] *implementing 4D regularly we won't be able to measure it and do a comparison"* (Participant 15).

10.3 Chapter Summary

This chapter first provided an explanation and discussion over the importance and use of models as 'abstractions' that facilitate our understanding. It documented the generalisability of Rogers (2003) innovation-decision process model, but also recognised some context-specific criticisms of it with regards to the construction sector. It was therefore, 'built upon' by incorporating several enhancements to produce a new innovation-decision process model specific for *modular technological process-based innovations* within construction. These enhancements were explained and then verified using the results of this multi-stage, mixed-method, research project. In this way, this chapter satisfies **Research Objective 5** by using a study of 4D BIM to develop a model that further informs innovation diffusion theory.

18 As contained in the qualitative data from Participant 41 regarding 'trialability' which was listed immediately above: specifically, regarding the importance of: "*setting very clear goals of 'this is what success/ failure looks like' and you have to score it, but it has to be very criteria driven … For me* [the answer is] *its - trial it, but if it meets the measured criteria then it works*".

Chapter 11: Conclusions

At the outset of the study two key problems were identified: the time predictability of construction projects, and problems with the diffusion of construction industry innovations. 4D BIM was identified as a possible solution to the time predictability problem, because of its potential for improving predictability when adopted as part of the construction planning process, and it was considered that a study of 4D BIM would provide a suitable research vehicle to contribute to the wider discussion of the problems facing the diffusion of construction industry innovations.

The aim of the study was then identified thus: '*to investigate the applicability of classic innovation diffusion theory to the adoption of 4D BIM by the UK construction industry'.* This aim was accompanied by the following research objectives:

1. Examine classic innovation diffusion theory and its applicability to the construction industry.
2. Analyse the planning of construction projects within the context of poor industry time predictability.
3. Examine, through the collection of empirical data, the development of 4D BIM in the UK construction industry.
4. Investigate the diffusion of 4D BIM within UK construction planning practice. Specifically, to *explore* and *explain*:
    - The construction planning functions that 4D BIM is principally being used for.
    - The extent of use of 4D BIM.
    - The innovativeness of members of this construction social system.
    - The rate of adoption of 4D BIM innovation.

- The consequences of 4D BIM.

5. Through a study of 4D BIM, develop a model that further informs innovation diffusion theory.

Use was made of mixed-method research whereby sequential qualitative, quantitative, then concurrent quantitative and qualitative (qual > quan > QUAN + QUAL) data collection techniques and analysis were deployed. The remainder of this chapter now provides summaries of the major themes, items and contributions arising from the study and is structured by addressing each research objective in turn. Eleven points of conclusion arising from the study are listed, and twelve predictions are made about the future outcomes of 4D BIM innovation adoption. To conclude the work research limitations and possibilities for future research are discussed, and recommendations for practice are made.

11.1 Research objective 1: Examine classic innovation diffusion theory and its applicability to the construction industry.

IDT considers how, why, and at what rate, new ideas and technology spread through cultures. It is specifically concerned with:

- How members of the social system determine a rate of innovation adoption because of their own perception of the characteristics of the innovation.
- The innovation-decision process.
- The effectiveness of communication channels.
- The classification of adopter categories.
- How key actors establish the norms and rules within a social system.
- How adopt-reject decisions are made.
- The consequences of innovation.

Criticisms of diffusion research were reflected upon, including: ‘pro-innovation bias’; ‘individual-blame bias’; ‘the recall-problem’; and issues of ‘equality’. Major diffusion research traditions were considered and many of the innovation types, methods and units of analysis related to diffusion studies were found to be applicable to construction management. The acknowledgement of the appropriateness of IDT in construction management research helps address the first research objective, which was also met through the identification of the need for further empirical research efforts into construction innovation diffusion. This was explored through focused use of the literature, which found that there was a relative paucity of empirical studies of innovation diffusion in construction, especially in large-scale survey research. Across studies that had been completed, it was argued that applied use of valid theoretical diffusion models were not being widely used as research methods, despite their acceptance across wider academic communities.

11.2 Research objective 2: Analyse the planning of construction projects within the context of poor industry time predictability

This objective was also met through the identification of key issues that were exposed within the literature review. The UK construction industry was contextualised in terms of its structure, complexity, key strategic challenges, and, across its multi, industry-; project-; and task-, level environment, it was recognised as a ‘complex dynamic system’.

At industry-level, key strategic targets are regularly formulated and communicated through industry initiatives, and whilst construction actors appear responsive, project delivery practices rarely alter. Any resulting improvements in project outcomes such as time predictability are measured across industry wide

Key Performance Indicators (KPI's) but these are marginal and are more closely associated with performance of the wider economy than true productivity. Environmental conditions such as low industry profit margins and attitudes to risk mean that the diffusion of process-related innovations, which could facilitate better practice, are infrequent and their adoption is rare.

Industry-wide system norms facilitate the generation and issue of unsystematic, ambiguous, poor quality production information at project commencement, and the ongoing amendments, refinements and variations to such content continues throughout the project duration until completion. At project-level, there is considerable uncertainty at the outset regarding: the envisaged product; project-objectives; and the means and processes to be undertaken. There are also significant complexity factors involving: general construction tasks; the physical environment; resource availability; and constraints that have to be managed. At task-level there is uncertainty over: the large volume of tasks to be undertaken; the complexity of their multiple interdependencies; task unfamiliarity and the variability of work, materials, locations and assemblies. At individual-task-level, concerns include: activity difficulty; complexity and analysability.

All the above factors contribute to an environment in which the construction planning process is undertaken. Further factors that arise within the construction planning process include: (1) the time horizon in which construction planning occurs; (2) the lack of accountability of the multitude of actors undertaking construction planning efforts; (3) the cognitive biases that these actors employ such as the 'planning fallacy' and 'optimism bias'; and (4) the over-reliance on traditional media which disproportionally emphasises project control over methods planning. These elements contribute to an increase in the 'transactional distance' between the originators and the recipients of planning information.

Consequently, these factors direct impact upon the quality and accuracy of construction plans and therefore contribute to poor construction project time predictability.

11.3 Research objective 3: Examine the development of 4D BIM adoption in the UK construction industry.

The study considered issues of general BIM adoption within UK practice as well as the development of 4D BIM adoption. The following sections take each issue in turn. Salient aspects of BIM were identified within the literature review, and the results from the semi-structured interviews with construction practitioners in both the exploratory (case study) and explanatory phases of the research are useful here.

11.3.1 The development of BIM adoption

In the exploratory research phase, a representative case study research project was undertaken. The unit of analysis in this case related to an individual organisation that had taken a top-down 'authority innovation-decision' to adopt BIM within their project delivery processes. The case study explored the phenomena of the impact of BIM adoption at project level and its impact upon a subset of members within this organisation. BIM innovation diffusion across comparable organisations, who have taken such top-down authority innovation-decisions on their projects, initially appeared to align with Rogers (2003) general innovation-decision process model, namely the process of Knowledge; Persuasion; Decision; Implementation and Confirmation[1]. Analysis of the data in this case identified that, although organisational leadership and knowledge was

1 Although ultimately, an enhanced model, specific to modular technological-process based innovations was generated over the course of this study.

effective in managing BIM innovation into use, there were 'people-problems' particularly in areas of information, communication and commitment which required cultural change. One identified challenge was in reconciling the differences between technologically-adverse and technologically-accepting persons, observed at individual level. The case study organisation could be considered to be an 'early adopter' of BIM innovation. One contribution to knowledge was the identification that such early adopters of BIM-innovation invariably duplicate much effort when having to employ hybrid project delivery processes (see Figure 11.1). These involve having to run several parallel processes to satisfy the competing demands and preferences between ICT-focused client and consultant transactions; inter-team preferences; and site-level paper based needs. Such effort duplication is predicted to be a cost, not only to early adopters, but to later adopters when undertaking their first BIM enabled projects.

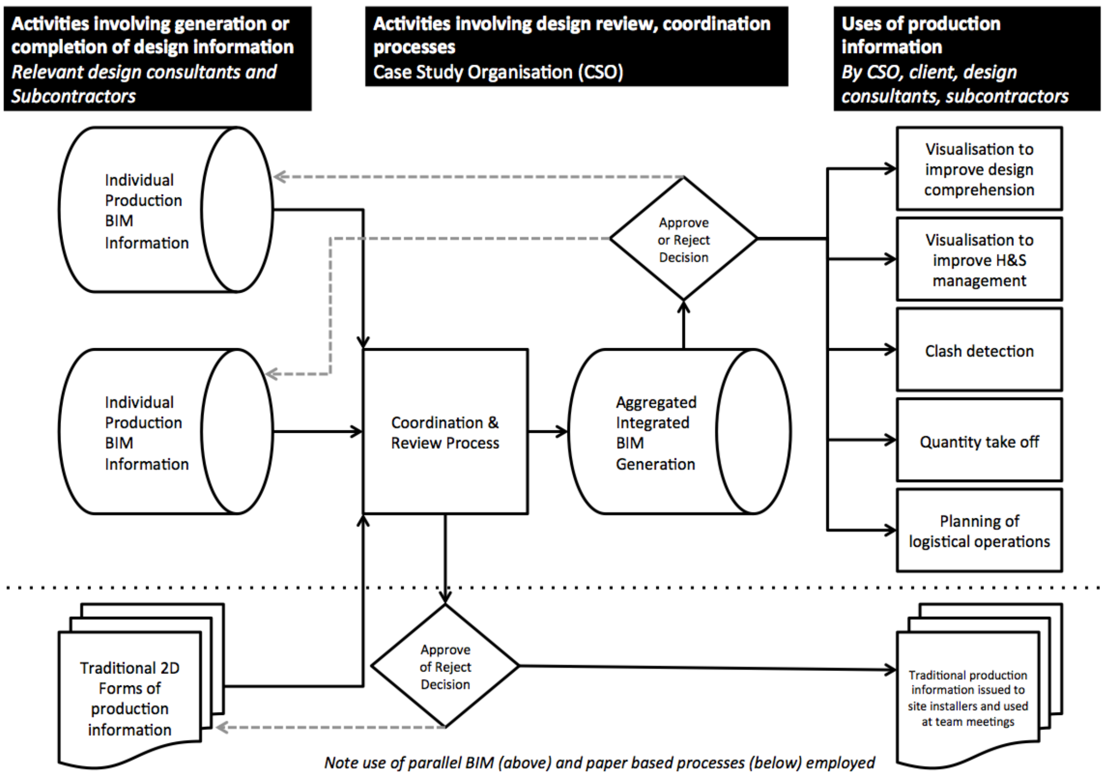

Figure 11.1: Hybrid project information delivery processes. Researchers own. For reference, identical to Figure 4.3

Later in the study semi-structured interviews were arranged with participants from across the AEC industry. Several of whom argued that without commitment from the entire Temporary Project Organisation (TPO), BIM would fail to provide full benefits and would create additional problems, including an immediate short-term problem of reduced productivity during practitioner learning curves. These interviews provided further confirmation that in order for constructors to obtain the benefits of BIM innovation, changes would be required in traditional project delivery practices, alternative design coordination strategies would have to be employed and model information would have to be repurposed to suit their needs. Further data generated from such interviews revealed that operatives at site production level would continue to work from traditional paper based design output (drawings) because of their ‘fields of experience’ confirming that duplication of effort, and having to run parallel document management processes and hybrid project delivery methods would be necessary. That all the above would result in additional work was a frequent and major concern, and despite the potential of attaining better understanding of design intent through 3D information representation and anticipated improvements in coordination achieved through clash detection processes, participants did not accept that there were any real improvements in the actual quality of the production information received. Some participants thought that ‘the problem of incomplete information’ would be amplified. This is where the multiple information streams that all generate partial information strands contributing to the overall design, consequentially result in a proliferation of additional design queries. This would also result in negative consequences of increasingly wasteful optioneering and exploration exercises occurring, whilst still awaiting missing information segments to be received to complete the design.

11.3.2 The development of 4D BIM adoption

This was addressed through questionnaire survey as detailed in Chapter 5, which was designed to address the following research questions: *'How have contracting organisations adapted their existing practices to utilise BIM innovation and improve project delivery?'* and *'How are contractors using 'alternative' BIM-based methods of planning construction work?'*. Results indicated a high level of BIM awareness and some experience of use of 4D BIM, particularly for work-winning, methods planning, and the visualisation and validation of construction processes. The study showed a general recognition of the value of 4D planning, its extent of use, and those elements of planning which were its principal targets. It also provided a view of drivers and barriers of 4D BIM innovation. The use of inferential statistics allowed several associations between the extent and use of BIM and 4D BIM innovations, and the characteristics of the user organisations to be determined. There was statistical significance in the relationship between company size and those companies that had intentions to implement BIM innovation. Larger companies of 250+ employees were much more likely to have already commenced implementing BIM Innovation than small (1-49) or medium (50-249) size organisations. There was a statistically significant relationship between reported organisational BIM maturity and company use of 4D BIM: revealing that the more mature the organisation in terms of BIM use, the higher the proportion of 4D BIM use in that organisation. For example, from within the responses that identified their company as having an organisational BIM maturity of Level 2+, proportions of 86% of 4D BIM use were found. Statistical significance was also found in the relationship between reported organisational BIM maturity compared against the perceived value of 4D BIM, but regardless of reported organisational BIM maturity all companies perceived there to be higher value of 4D planning than not, however differences were much more pronounced in between ‘L0 organisations’ and the ‘L1’ and ‘L2+’ organisations. Several conclusions could be drawn from this survey:

i. There is a relationship between company size and those companies that plan to implement BIM innovation. Examination of the data revealed that larger companies had already commenced implementing BIM at the time the survey was undertaken.

ii. There is a relationship between the reported organisational BIM maturity compared to company use of 4D BIM. Examination of the data clearly proved[2] that, *as organisational BIM maturity increases, so does the company use of 4D BIM*.

iii. There is a relationship between reported organisational BIM maturity compared to the perceived value of 4D BIM innovation. Examination of the data reveals that *as organisational BIM maturity increases so does the perception of the value of 4D BIM*.

11.4 Research objective 4: Investigate the diffusion of 4D BIM innovation within UK construction planning practice

This research objective contained the following series of sub-objectives.

11.4.1 Explore and explain the construction planning functions that 4D BIM is principally being used for

Both questionnaire surveys contributed here. As indicated above, findings from the first questionnaire identified that, at that time, 4D BIM was found to be principally used for winning work, methods planning, communicating timescales, and the visualisation and validation of construction processes. A subsequent statistical test of relative importance performed on data gathered from the second

2 X2 test statistic of .000

questionnaire reinforced that the highest ranked advantages of 4D BIM (relative to traditional construction planning practices), relate to its potential to alleviate problems of communication and understanding. The highest ranked items focused on the usefulness of 4D planning for: visualising the construction process; facilitating understanding of the construction process; and communicating working space.

11.4.2 Explore and explain the extent of use of 4D BIM.

At this stage, the extent of use of 4D BIM seems primarily limited to the communication of methods and timescales with little evidence of exploitation of its full potential for assessing, validating and controlling project timescales. Across both surveys, approximately two-thirds[3] of respondents identified that they, or someone else in their organisation had used 4D BIM for construction planning practice. However, extent of use seems to be primarily limited to work winning, and the communication of methods and timescales.

11.4.3 Explore and explain the innovativeness of members of the construction social system

It was determined that organisational characteristics were more important than individual user characteristics in determining user innovativeness. No significant associations were found between the independent variables identified as important within IDT (education, household income, job function, job level) when tested against the personal adoption of 4D BIM. Specific conclusions drawn from survey research at this stage of the study however identify that:

i. There is a relationship between company size and reported organisational BIM Maturity, with the data providing strong evidence

3 66.1% then 62.8% respectively.

that *larger companies are more likely to have greater organisational BIM maturity*[4].

ii. There is a relationship between company size and personal use of 4D BIM. Examination of the data proves[5] that *there is more likely to be personal use of 4D BIM within larger companies*.

iii. There is a relationship between reported organisational BIM maturity and personal use of 4D BIM. Examination of the data clearly proves[6] that *the higher an individual's perception of their organisations BIM maturity, the more likely that personal use of 4D BIM will occur*.

11.4.4 Explore and explain the rate of adoption of 4D BIM Innovation

Here, tests of correlation were performed to explore the typical time lag from initial awareness to first adoption of 4D BIM. Several tests of association found statistical significance related to the 'compatibility' and 'trialability' of this innovation. Additionally, the relative advantage of the use of 4D BIM for communicating the construction plan, and the factors that influence company decision-making were considered important. Specific conclusions that help explain the innovation adoption rate are that:

i. There is a relationship between the first impressions formed about 4D BIM and personal use of 4D BIM. Examination of the data appears to reveal that *there is more likely to be subsequent personal use of 4D BIM if an initial favourable impression is formed*.

ii. There is a strong positive relationship between the timing of first awareness and the timing of first adoption of 4D BIM (r = .764). The usual

4 These variables were originally tested for association during the preliminary research period, but at that stage no associations were found (Fisher's Exact Test gave a close to significant association of .051), however some identical questions were included in the explanatory questionnaire allowing the relationship to be and thus proved (Fisher's Exact Test Statistic of .001).

5 X2 test statistic of .002

6 Fisher's Exact Test statistic of .000

time lag recorded between awareness and adoption can be confirmed as being between 2.38 – 3.00 years (28.5 - 36.0 months). *More than half (58.3%) of the variance in the timing of first adoption can be attributed to the timing of first awareness.*

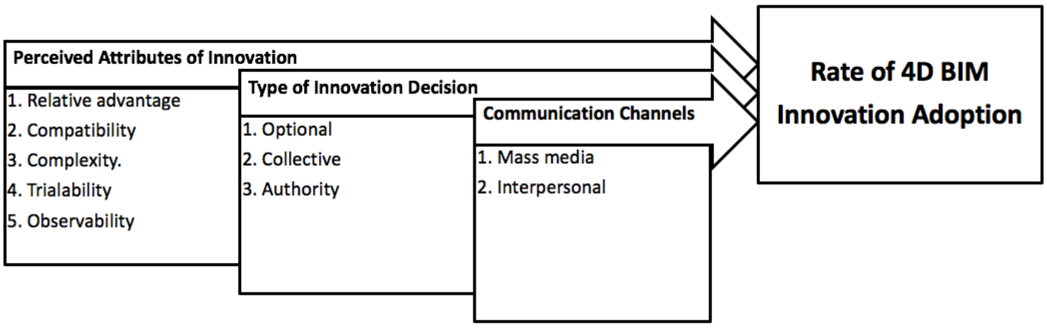

Figure 11.2: Variables determining the rate of 4D BIM innovation adoption. Adapted from Rogers (2003). For reference, identical to Figure 6.2

iii. There is strong evidence[7] to suggest a relationship between the compatibility of 4D BIM with construction planning practice, and the personal adoption of it. Analysis of the data reveals that whilst adopters and non-adopters are equally alike in considering 4D BIM to be compatible with current planning practices, *those who have adopted 4D BIM are far less likely to consider 4D BIM incompatible with current planning practices*.

iv. It has been proven[8] that there is a perceived need to experiment with 4D BIM prior to adoption and using it to plan real construction work. Analysis of the data appears to suggest that whilst adopters are equally likely to agree or disagree with the need for experimenting or trialing of this innovation (i.e. there is no real trend in this category), *those who have not yet adopted 4D BIM much more strongly consider there to be a need to trial it before using it to plan real construction work*.

7 Fisher's Exact Test statistic of .026

8 Fisher's Exact Test statistic of .005

v. There is also strong evidence to suggest[9] that a relationship between company size and innovation adoption decision types exists which affects adoption rate. Innovation in larger companies (250 persons+) is linked to overall company strategy, and individuals working for these companies, require 'authority-decisions' to be made before adoption and use can occur. In contrast, there appears to be more flexibility for SMEs.

Whilst there was no statistical relationship found between the perceived relative advantages of 4D BIM compared to personal adoption and use of 4D BIM Innovation, a Fishers Exact Test did show a statistic of .079 for the relative advantage of using 4D BIM for communicating the construction plan, which is slightly outside the margins of significance. Therefore it would appear from several of these conclusion points that such relative advantage of being able to communicate the construction plan using 4D methods means that this innovation is worth adopting, but *in order for 4D BIM to diffuse more rapidly, potential adopters have to be convinced that 4D BIM is a modular innovation, i.e. that it produces significant improvements, but it does not require alteration of other system-level components*[10]*, and that it is compatible with existing planning practices*, *and can be trialed in a safe environment prior to use on a live construction project*.

11.4.5 Explore and explain the consequences of 4D BIM.

The study revealed several such consequences. Firstly, planning output created using 4D methods will increase interrogation of the plan from several stakeholders. Increased input from members of the construction team is generally welcomed, although the additional efforts in exploring multiple ongoing

9 Fisher's Exact Test statistic of .019

10 See Slaughter (1998; 2000)

‘what if’ scenarios were a concern for the level of resource required to undertake planning operations. ‘Construction team interactions’ are seen as helping validate the plan, resulting in increases in precision and detail that are also better communicated to the workforce helping improve construction project time predictability and producing opportunities for potential time savings. However, the prospect of input from all project stakeholders was not particularly welcomed. There were concerns that increased plan-transparency may result in negative interactions with the client team, particularly in analysing progress position during the construction phase. Conversely such increased plan-transparency and increased interactions with the client team may increase levels of ‘functional conflict’ (see Emmitt and Gorse, 2003; Gorse, 2003) which may in turn help in establishing and agreeing more realistic project durations at the preconstruction stage.

Additional consequences include expectations that greater efforts will be made once the innovation is adopted to capture data to be able to prove the benefits and justify innovation-adoption. This should result in the capture of data that increases organisational knowledge of the production output rates actually achieved at individual task level. In turn, this increased certainty in the data used for planning task level operations will support project-wide decision-making, and contribute to a construction plan with a realistic project duration that should improve certainty of delivery. Analysis of this data has provided the researcher with an opportunity to make several predictions about the direct consequences of 4D BIM innovation adoption. These are:

i. *Planning resource and planning effort will increase to levels higher than would previously have occurred.*
ii. *Plan interrogation will increase, leading to improvements in plan quality.*

iii. *Increased plan quality will, therefore, lead to improvements in time predictability.*

iv. *Increased plan quality and interrogation, will also lead to reductions in project time durations, which would otherwise never have occurred.*

v. *Plan transparency will increase, leading to more functional conflict with stakeholders than would otherwise have occurred.*

vi. *Increased plan transparency, will also lead to more frequent negative interactions with the client team than would otherwise have occurred.*

Because of these direct consequences, a series of predictions can also be made about the indirect consequences of 4D BIM innovation adoption. These are:

i. *To prove the benefits of 4D BIM adoption, efforts to capture data on the actual task durations realised will be increased.*

ii. *Data captured about actual task durations achieved will increase organisational knowledge.*

iii. *Greater organisational knowledge about actual task durations will result in improvements in future organisational planning quality.*

iv. *Improved organisational planning quality will result in more realistic anticipated project durations than would otherwise have been generated.*

v. *More realistic anticipated project duration data will be available to inform client decision making at tender stage.*

vi. *More realistic anticipated project duration data will lead to greater improvements in time predictability than would have previously been achieved.*

11.5 Research objective 5: Through a study of 4D BIM, develop a model that further informs innovation diffusion theory.

Despite participant assertions of the low level of innovation in construction, the industry is particularly good at adopting specific types of innovation, such as technical innovations. These can be classified as ‘modular’ where a newer, superior product or technology can quickly substitute and take the place of an inferior original product or technology without altering other system level components. In contrast, literature (Slaughter 1998; Winch, 1998; Loosemore, 2014) shows that because of a need to solve specific project-related problems, ‘incremental innovations’ which offer minor improvements on existing practice, do occur regularly within Temporary Project Organisations, but only infrequently diffuse back within companies because of problems with organisational learning. As such, the rate of process-based innovation adoption often suffers in comparison with product or modular based innovations. Construction norms of fragmentation, ever-changing production locations, the market environment and industry business practices were identified by participants as contributing to the low rate of diffusion for process innovation types.

This study of 4D BIM innovation diffusion has been used as a vehicle to make an original research contribution to innovation diffusion theory for the diffusion of a particular innovation type - a ‘modular technological process-based innovation’. Two existing innovation models were considered when analysing the data against this innovation type: The model of construction innovation processes developed by Winch (1998) and the innovation-decision process model developed by Rogers (2003).

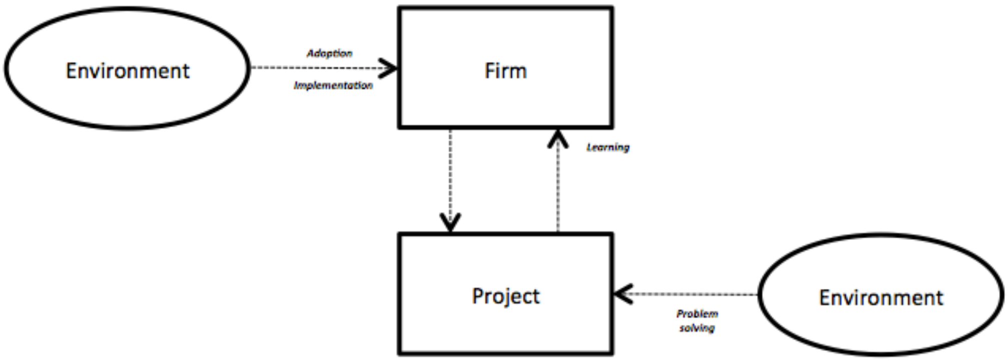

Figure 11.3: Construction innovation processes. Reproduced from Winch (1998). For reference, identical to Figure 4.4

Despite recent literature that argues that construction innovations can only be successfully implemented if driven by lower ‘project-level’ staff (Arayici *et al*., 2011; Davies and Harty, 2013a), the rich data and wide range of perspectives received from participants interviewed was sufficient to confirm that the multi-directional model of construction innovation implementation produced by Winch (1998) remains true, accurate and does not require amendment. Both top down and bottom up movements are necessary. Winch (1998, p273) states: *“new ideas can either be adopted by firms and implemented on projects or result from problem-solving on projects and can be learned by firms. Both are, ‘a priori’, as important as each other in the construction innovation process”*.

11.5.1 A new model of the innovation-decision process for modular technological process based innovations.

Rogers (2003) model has been amended specifically to reflect the process that decision making units go through when considering adoption or rejection of modular technological process-based innovations. Key to appreciating the model is understanding that in construction the process occurs in an environment of extreme uncertainty in a multi-level, structurally complex yet dynamic system. At industry-level, construction actors operate within ‘red oceans’ achieving low profit levels while being exposed to high levels of risk. Because of these factors, organisational decision-making units are preoccupied with achieving successful operational project delivery at least cost, rather than exploring and investing in alternative project delivery processes. At project-level, assets are delivered through contractual engagement with multiple inter-dependent companies as part of a temporary project organisation. Any process based innovations that affect the TPO will have to diffuse across several organisational boundaries in order for the benefits to be realised, a process that requires multiple levels of engagement and commitment in order to be successful. Adoption and implementation of any technological innovations also require time for learning to occur which can result in a reduction in productivity which can be unacceptable to construction actors. It is little surprise that given the above, construction actors choose to engage in traditional delivery practices rather than consider adoption of process based innovations and amend their usual project delivery practices.

This new model shows 6 more involved stages, and includes an additional 'environmental factor', as well as several 'decision-action points' and 'outcome-types'. Figure 11.4 shows these enhancements as black text boxes. The modifications to Rogers' original model were verified from the findings arising throughout this multi-stage, mixed-method, research project. Chapter 10 evidences this, and provides the full description of this new model, although a briefer explanation now follows.

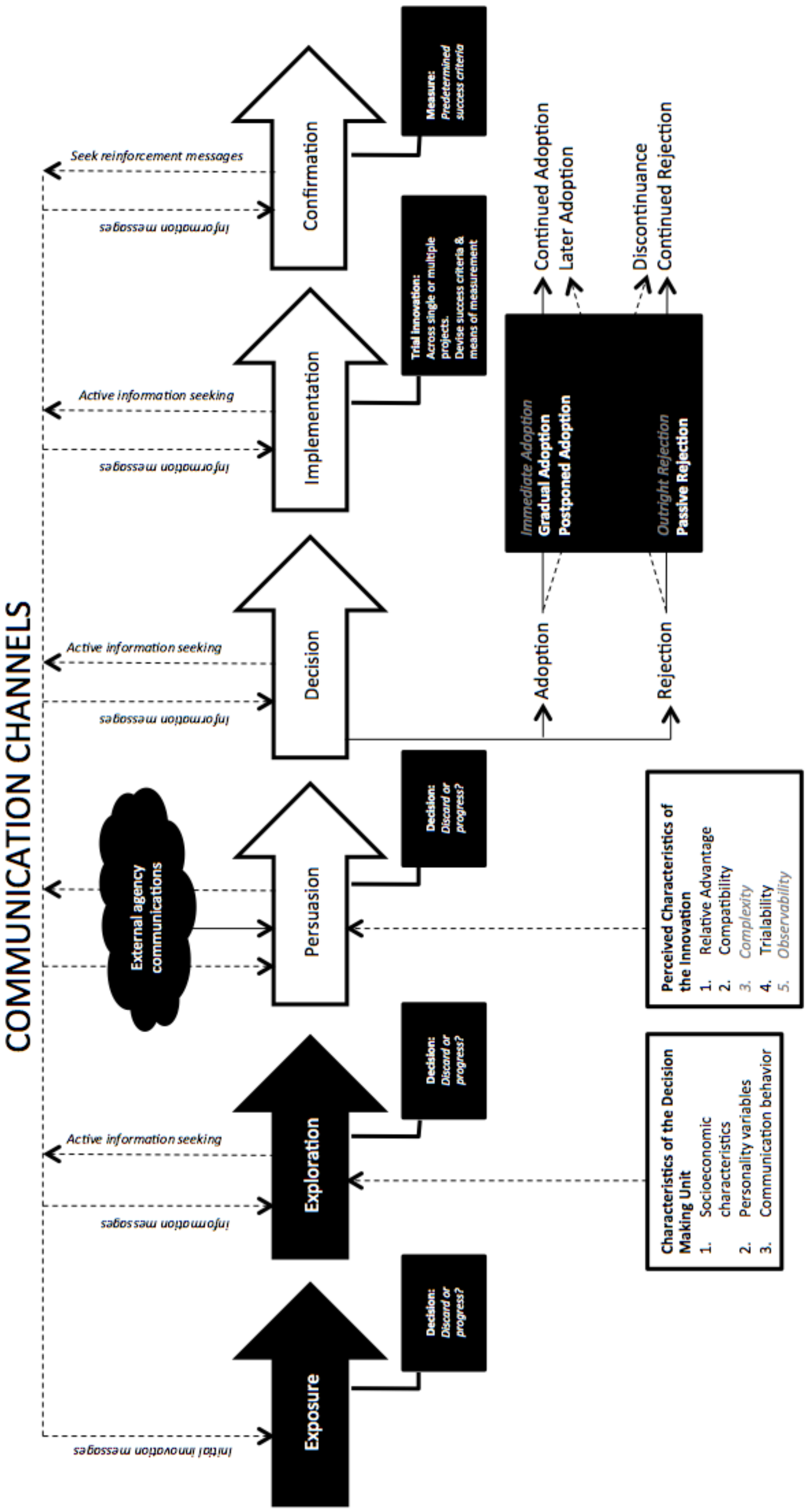

Figure 11.4: New model of the innovation-decision process as applicable to modular technological process based innovations. For reference, identical to Figure 10.1

Two additional stages (I) ‘exposure’ and (II) ‘exploration’ replaced the traditional knowledge stage. An additional factor of ‘external agency’ influences the (III) persuasion stage. Additional decision points occur at each of these stages requiring the decision-making unit to either discard these messages or progress to the next stage in the process. The outcomes of the (IV) decision stage are refined to identify five distinct outcome types, the typical outcomes of ‘gradual-adoption’, ‘postponed-adoption’ or ‘passive-rejection’, and the rarer outcomes of ‘immediate-adoption’ and ‘outright-rejection’. These outcome types provide more depth of understanding to the types of innovation-decisions made about general technological process based innovations than the high-level adoption and rejection outcomes identified by Rogers (2003) in his more general model of the innovation-decision process. The multiple implications of choice identified within the original model remain, i.e. regardless of the exact decision type, any initial decision to adopt can be followed by continuous adoption or later discontinuance of the use of the innovation. Conversely any initial decision to reject an innovation can be followed by continuous rejection or conversely by later adoption. At the (V) implementation stage, additional action points to ‘trial’ the innovation across single or multiple projects; ‘devise innovation success criteria’, and; perform ‘means of measurement’ are included. As a consequence of this stage, use of the innovation may also see the manifestation of ‘reinvention’. For the (VI) confirmation stage to be successfully realised, the additional action point of ‘measurement of innovation success factors’ should occur. This allows the results of the benefits and learning from initial use of the innovation to be communicated, if this action does not occur then adoption of the innovation will be vague and indistinct rather than definite. This model also differs from the classic innovation-decision process model by recognising that after the initial ‘exposure’ stage, all communication channels involve two-way acts of communication with ‘active information seeking’ by the decision-making unit occurring supplementing the innovation information messages received. At the final stage ‘confirmation’, this two-way communication requires that ‘reinforcement messages’ are also sought by the decision-making unit to reinforce the innovation information messages received.

11.6 Limitations of the study and recommendations for further research

The limitations that had the greatest potential impact on the quality of the findings and in addressing the research objectives, related to the comprehensiveness of the reviewed literature, the sampling frame used particularly for the more quantitative parts of the study, and the non-inclusion of several independent research variables in the explanatory questionnaire survey.

When reflecting upon these limitations, it can be argued that whilst the production of a systematic review of the literature may have been of some additional benefit, the choice to use a more focused narrative-type literature review ultimately helped best present the work of the key theorists and the most influential sources across the themes of IDT, construction planning, BIM and 4D BIM.

Before addressing the second limitation, it is worth repeating that the research choice was explicitly determined as being a mixed-method study informed by a pragmatist philosophy. It combined qualitative findings from an initial case study, with quantitative findings from two questionnaires, before a final round of semi-structured interviews provided further qualitative data. Therefore, a second limitation in this research project, relates to the use of a non-probability sampling technique for the quantitative elements of the study. It was identified earlier in the study that the population of interest for this study was those UK construction sector organisations looking to innovate by incorporating BIM and 4D BIM within their project delivery practices. Relevant individuals (primarily construction planners and project managers) who represented such organisations, were the focus of the data collection strategies.

For true random probability sampling to occur, the quantitative elements of the study should have selected either a ‘simple’, ‘systematic’ or ‘stratified’ random sampling technique across this population. Instead as it focused on those persons with specific interest in the subject matter[11], purposive sampling methods were used. For the initial case study, a general level of interest was helpful. For the two rounds of quantitative data collection, the two focused questionnaires were designed to be of interest to those that were in some way involved in the planning of construction projects - as these were best able to address the research objectives. These questionnaires were titled (in order) ‘Planning and controlling construction projects using BIM and Virtual Construction’ and ‘Investigating the diffusion of 4D BIM innovation’. The final round of semi-structured interviews were held with participants who had effectively ‘self-selected’ themselves having already completed the second questionnaire and volunteered to undertake interview. From a pragmatist perspective, when using mixed methods research such participant selection is not truly considered a weakness. However, if the quantitative elements of the study are considered in isolation, use of such a non-probability sampling frame

11 As a further caveat, it should be considered that the study was undertaken over a time period when UK construction organisations were effectively being exposed to innovation messages about BIM by many external agents. Furthermore, these companies were also being directed to adopted BIM prior to a deadline of April 2016 if they wanted to be considered for appointment to work on centrally procured public sector projects. At the outset, the researcher could not predict how much impact the ‘2016 BIM mandate’ would have upon the final results of the study. Whilst this environment, and such a governmental policy lever meant a great deal of interest from potential research participants, it also meant it was impossible at the outset of the study to ascertain the ongoing extent of influence of such external agency upon the participants themselves. Quite simply, would the thoughts, words and actions of the participants have been similar if no mandate had existed, or would the results produced have been significantly different?

may lead the reader to believe that the ability to make any generalisations about this population at all is restricted.

Finally, it is worth noting that, although it was not included as a variable in this study, variations in the type of procurement method encountered by organisations may have an impact on the rate that they adopt innovations, on the basis that construction organisations rely on their projects to feed their knowledge base. For example, it might be hypothesised that constructors that work predominantly in design and build (or D&B within PFI) environment would find the adoption of 4D BIM is ‘easier’ than those operating predominantly in (‘traditional’) client-led ‘design-bid-build’ procurement systems. The sensitivity of an organisation’s innovation adoption, or that of its project staff, to variations in procurement route were outside of the scope of the current study, though it would represent an interesting topic for further investigation. The reasons for this delimitation in the present study are two-fold: the first being the pre-eminence of forms of contractor-led design (D&B, Novated D&B, PFI/PPP) in current construction projects and the second, that respondents and their companies would, in any case, be likely to be exposed to all procurement types. This means that overall, exposure to different procurement methods was considered unlikely to have had an effect, either on individuals in the study or their organisations.

The impact of procurement was considered elsewhere in the work, specifically in the literature review chapter, which argued:

- How procurement strategy dictates ‘when’ planning occurs (Section 2.2).
- How the order of design activities is affected by procurement strategy (2.3).

Procurement was also considered in the results of other empirical stages of the work, specifically:

- In the exploratory questionnaire, where participants were asked to identify their preferred procurement strategy from a set list of response options (design and build was the most frequent response selected).
- In the same questionnaire, where participants were asked to identify the barriers to BIM adoption also from a set list of response options (the 'structure of procurements and contracts' was identified as a mid-range barrier to BIM adoption).
- During the analysis of the final round of semi-structured interviews where it was noted: "*Procurement tender processes were discussed as both enabling and preventing innovation diffusion. This is largely dependent upon project stakeholder attitudes [however] … within alternative procurement practices such as two-stage tender opportunities, participants did see the greater availability of time as useful in the promotion of innovations*".

Therefore, as noted above, an interesting topic for further investigation at a 'micro' (i.e. project-, rather than organisational-level) would be to consider whether project procurement mechanisms affect the adoption of the innovation.

11.6.1 Looking forward with recommendations for future research

There are several ways in which this research could be advanced. Efforts should concentrate on: the contribution made to universal IDT; the consequences of general BIM use; and the diffusion of 4D BIM specifically at industry- or project-levels.

Any research focussing on modular technological process innovations, could make use of the new innovation-decision process model produced by applying, testing, or validating, the model. Greater focus on the exposure and exploration stages, using qualitative research methods, could help generate further knowledge about these initial stages of the innovation-decision process. Efforts directed toward the decision, implementation and confirmation stages are of equal importance. Exploration and confirmation of the five decision outcome types articulated in this model particularly warrant further research, and survey research could reveal much about the frequency and reasons behind these outcome types. Efforts within organisation to trial, measure benefits, and capture learning around such innovations, would be of great value and could potentially be achieved through case study research.

Future research into general BIM use is expected to challenge its identified benefits and as such, the implications of one of the findings of this work is particularly worthy of follow up. The single project level case study revealed use of hybrid methods of managing project information across the project delivery process. Such an approach contains considerable processes waste, and it can be considered that perversely, it can make use of BIM innovation less efficient. Future case study or survey research could confirm if this case represents a typical method of working with BIM across the sector as well as reveal any alternative approaches used.

Regarding 4D BIM diffusion, the core focus of this work has been specifically retained on organisational-, rather than industry-, or project-level adoption. IDT focuses on the adoption/rejection of an innovation by ‘decision making units’ and here, relevant organisations as represented by their key personnel embodied these units. Follow on work could instead focus on industry-, or project- level diffusion. A follow up quantitative survey could be designed to determine the exact take up and use of 4D BIM across industry. Such a study would have to use random probability sampling techniques, rather than the purposive sampling approach used here, and as such, difficulties in attaining appropriate response rates should be considered. Conversely project-level, studies to determines if adoption of 4D BIM is dependent upon project-level variables would also be of value, as the omission of variables involving project governance or procurement mechanism have specifically been identified as a limitation of this study. Other project-level variables such as ‘type’ of project (by size, funding, or type of building) could also be tested in future research to attempt to determine if they affect the adoption of the innovation.

11.7 Implications and recommendations for practice

Constructor organisations wishing to improve the time predictability of their projects, and who understand the benefits to be had using 4D BIM could use the findings of this research to manage a more focused adoption and implementation of this innovation in the planning practices of their employees. As a minimum, the advantage of being able to communicate the construction plan using 4D methods rather than traditional formats mean that this innovation is worth adopting. Although 4D BIM has obvious value for winning work, planning methods, communicating timescales, and visualising and validating construction processes, there is also much latent potential to offer in the assessment, validation, and controlling, of project timescales. To exploit the full range of benefits, such organisations should be aware of the following issues.

For organisations with no organisational BIM capability at all:

- There will be initial start-up costs encountered, before any return on investment is realised. As with any innovation, investment is needed. Necessary hardware and software will require purchasing and adequate and appropriate training options should be investigated.
- Employee productivity is likely to reduce during initial 'learning curves'.
- Efficiency is also likely to suffer on any initial BIM-enabled projects. This is because of the nature of temporary project organisations, and the understanding that hybrid project delivery processes may have to be employed. There are already established difficulties with exchanging project information between organisations and fragmentation issues within supply chains is likely to continue until some basic BIM capability is embedded throughout the TPO

For organisations with some organisational BIM capability, who have already experienced the above:

- Adopters of 4D BIM do not consider it to be incompatible with current planning practices.
- Ultimately organisational characteristics are more important than individual user attributes in the adoption of 4D BIM.
- Organisational BIM Maturity will ultimately determine the perceptions of value of 4D BIM, and ultimately the use of 4D BIM by employees.
- The adoption of 4D BIM by individual employees is directly related to factors around the first awareness of the innovation, specifically around favourable first impressions and timing.
- It is advantageous if the innovation can be trialed in a safe environment prior to use on a live construction project.

- Decisions to adopt 4D BIM by individuals are closely linked to overt adoption decisions made by organisational upper management. As such, any absence of such decisions will slow individual adoption.
- The production of 4D plans requires additional work. Increases in planning resource, and planning efforts are likely needed.
- Interrogation of the construction plan is likely to increase. This should lead to improvements in plan quality, but also to more interactions and (functional) conflict with project stakeholders.

11.8 End

4D BIM is a modular technical process-based innovation, that has the potential to provide improvements in construction planning and in project time performance. These outcomes also may help address the problem of construction project time predictability. However, the spread of such innovations is not automatic, and their 'take-up' is not universally accepted. Because of this, the research aim was to investigate the applicability of classic innovation diffusion theory to the adoption of 4D BIM by the UK construction industry. In the study, key variables from classic IDT were used alongside various constructs derived from construction management literature. In considering the development and diffusion of 4D BIM several contributions were made to the fields of construction management and IDT. Most prominently by way of an update to Rogers (2003) innovation-decision process model, additional stages, decision-action points and outcomes were added, specifically for the process that decision making units go through when considering adoption or rejection of such modular technological process-based innovations.

Appendices

Appendix A: Abstract and citation details of research output produced as part of this thesis (chronological order).

Appendix B: Abstract and citation details of additional, indirect research output arising.

Appendix C: Schedule of research participants.

Appendix D1–D4: Research Instruments.

Appendix E1–E4: Theoretical underpinnings of key questions in research instruments.

The implementation and use of 4D BIM and Virtual Construction

Barry J. Gledson and David Greenwood

Abstract: The 2013 UK Government construction strategy, presented at its 'Construction Summit' set targets for 50% faster project delivery and reductions in the overall delivery time for new build and refurbished assets. Despite the best efforts of constructors, who have considerable in house experience, skills and knowledge in project delivery, more than half of all UK construction projects exceed their agreed time schedules; with current data revealing the worst performance for 12 years. The concurrent drive for all centrally procured public construction projects to be working at BIM Level 2 by 2016 is seen as an important step in improving the quality of project information, which, in turn, should result in improvements in project predictability, including predictability of both time and cost. The current research investigates how contracting organisations have adapted their existing practices to utilize BIM and improve project delivery. As part of the work a quantitative survey was undertaken that focused upon the current use of virtual construction. Results show a high level of BIM awareness and a more limited degree of experience of using virtual construction practices to improve construction planning. There was, however, a generally high level of recognition of the potential value of 4D planning. With additional data, the study will investigate whether potential benefits of 4D planning are being actualised, as well as exploring associations between the extent and nature of its use and characteristics of the user organisations.

Keywords: 4D planning, building information modelling (BIM), construction planning, construction scheduling, virtual construction.

Citation: Gledson, B. and Greenwood, D. (2014) The implementation and use of 4D BIM and Virtual Construction. In A. B. Raiden and E. Aboagye-Nimo, eds. *Proceedings 30th Annual ARCOM Conference,* Portsmouth, UK 1-3rd September 2014: ARCOM, pp. 673–682.

Download paper: http://www.arcom.ac.uk/-docs/proceedings/ar2014-0673-0682_Gledson_Greenwood.pdf

Investigating the diffusion of 4D BIM Innovation

Barry Gledson

Abstract: UK Government regularly applies challenging strategic targets to the construction industry, chief amongst these are requirements for more rapid project delivery processes and consistent improvements to the time predictability aspects of on-site construction delivery periods. Latest industry KPI data has revealed a recent increase across measures of time predictability, however more than half of UK construction projects continue to exceed agreed time schedules. The aim of this research was to investigate the diffusion of 4D BIM innovation as adoption of this innovation is seen as a potential solution in response to these targets of construction time predictability. Through purposive sampling, a quantitative survey was undertaken using an online questionnaire that measured 4D BIM innovation adoption using accepted diffusion research methods. These included an exploration of several perceived attributes including compatibility, complexity, observability and the relative advantages of 4D BIM innovation in comparison against conventional functions of construction planning and against stages of the construction planning processes. Descriptive and inferential analysis of the data addresses how the benefits are being realised and explore reasons for adoption or rejection decisions of this innovation. Results indicate an increasing rate of 4D BIM innovation adoption and reveal the typical time lag between awareness and first use.

Keywords: 4D planning, building information modelling (BIM), construction planning, innovation diffusion.

Citation: Gledson, B. (2015) The diffusion of 4D BIM Innovation. In A. B. Raiden and E. Aboagye-Nimo, eds. *Proceedings 31st Annual ARCOM Conference,* Lincoln, UK 7-9th September 2015: ARCOM, pp. 641-650.

Download paper: http://www.arcom.ac.uk/-docs/proceedings/67b641c691f1c4c7904d26181b7b6aa7.pdf

Hybrid project delivery processes observed in constructor BIM innovation adoption

Barry J. Gledson

Purpose: Exploratory research was undertaken focusing upon an innovation adoption decision taken by a regional UK division of a large international contracting organisation implementing BIM into their project delivery processes. The aim of this study was to gain new insights through observations of the process and analysis of the views of employees about organisational BIM adoption during the implementation stage of the innovation-decision process.

Design/methodology/approach: Case study research was performed focussing on initial BIM projects delivered by an early adopter organisation. Observations and semi-structured interviews were used as part of a data collection strategy and an iterative research approach was adopted.

Findings: During implementation stages of BIM innovation adoption, organisations may have to make use of hybrid project delivery methods on initial adopter projects, whilst also working concomitantly with existing systems, processes and personnel not yet ready to adapt to BIM methodology.

Originality/value: The work captures previously unseen phenomena of how such an organisation and its staff have adapted to BIM innovation adoption during a programme of organisational change. The identification of hybrid project delivery processes has generated further implications for practice and research into the effectiveness of construction production information management.

Keywords: Building information modelling (BIM), Case study, Diffusion, Industrialised Building (IB), Innovation.

Citation: Gledson, B.J. (2016) Hybrid project delivery processes observed in constructor BIM innovation adoption, *Construction Innovation*, 16(2). Pp. 229-246

Download paper: http://www.emeraldinsight.com/doi/abs/10.1108/CI-04-2015-0020

Surveying the extent and use of 4D BIM in the UK

Barry J. Gledson and David J. Greenwood

Abstract: More than half of construction projects exceed their agreed time schedules. Attempts to remedy this have been monitored over a number of years in the UK using standard industry KPI measurement data. The aim of this research was to investigate how contracting organisations have adapted their existing construction planning practices by using 4D BIM to improve project delivery and time predictability. In the light of the current lack of robust case-based evidence in support of this premise, a survey of 136 construction practitioners was conducted to measure the extent and use of 4D BIM in the UK and the perceptions of its value. Results indicated a high level of general BIM awareness, and some experience of 4D BIM for work winning, methods planning, and the visualisation and validation of construction processes. The study revealed the perceived value of 4D BIM, the extent of its use, and those elements of planning which were its principal targets. It also provided a view of the drivers and barriers for 4D BIM adoption. Several associations were found between the characteristics of user organisations and the extent and use of 4D BIM (and BIM more generally). The study uncovers the areas in which 4D BIM is believed by practitioners to be more effective than traditional means of construction planning. The conclusion is that the benefits of 4D BIM are considered to be less concerned with creating, validating and controlling project timescales (all of which still require the skills of experienced practitioners) but are more related to handling and communicating information. Given that these aspects are, using traditional 2D methods, considered to be a primary cause of 'poor predictability', the study supports the value of 4D BIM in improving project delivery.

Keywords: 4D planning, building information modelling (BIM), construction planning, construction scheduling, virtual construction.

Citation: Gledson, B.J. and Greenwood, D.J. (2016) Surveying the extent and use of 4D BIM in the UK, *Journal of Information Technology in Construction (ITcon)*, Vol. 21 No. April, pp. 57–71.

Download paper: http://www.itcon.org/cgi-bin/works/Show?2016_4

Exploring the consequences of 4D BIM innovation adoption

Barry Gledson

Abstract: UK Government has ambitions for improvements in construction project time predictability. Better management of construction innovations into use could help with this aspiration, but despite a recent drive advocating Building Information Modelling (BIM) innovation adoption, the construction industry is still perceived to have low innovation levels in comparison with other sectors. The purpose of the work was to explore the use and consequence of 4D BIM innovation in relation to construction time predictability. Insights were gained using semi-structured telephone interviews conducted with a range of construction practitioners. Several dimensions of consequences of 4D BIM innovation adoption were considered including desirable/undesirable consequences, direct/indirect consequences and anticipated/unanticipated consequences. In addition to consideration of the benefits and demand for 4D BIM, the results also reveal criticisms over current planning mediums and process inefficiencies. Results also reveal concerns over the additional work required to create 4D plans, and the quality of the plans produced.

Keywords: 4D planning, Building Information Modelling (BIM), Innovation, Innovation diffusion.

Citation: Gledson, B. (2016) Exploring the consequences of 4D BIM innovation adoption. In P W Chan and C J Neilson (Eds.) *Proceedings of the 32nd Annual ARCOM Conference*, 5-7 September 2016, Manchester, UK, Association of Researchers in Construction Management, Vol 1, 73-82.

Download paper: http://www.arcom.ac.uk

The adoption of 4D BIM in the UK construction industry: An Innovation Diffusion approach

Barry J. Gledson and David J. Greenwood

Purpose: - More than half of UK construction projects exceed their planned time schedules. This is a trend that has been recorded over a number of years using standard industry KPI data. Despite these failings, UK Government introduced a strategic target of delivering future projects 50% faster than the project durations achieved in 2013. To realise this strategy requires, amongst other things, more rapid project delivery processes, and consistent improvements to the time predictability aspects of on-site construction delivery periods. There is an expectation, supported by some evidence, that the adoption of 4D BIM by UK project planners will contribute to this. The aim of the present research was to investigate how this adoption has taken place, using Rogers' Innovation Diffusion theory as a basis.

Design/methodology/approach: A survey of 97 construction planning practitioners was conducted to measure 4D BIM innovation take-up over time. Classic innovation diffusion research methods were adopted.

Findings: Analysis of the data addresses how the benefits of 4D BIM are being realised and explore reasons for adoption or rejection decisions of this innovation. Results indicated an increasing rate of 4D BIM adoption and reveal a time lag between awareness and first use that is characteristic of this type of innovation.

Research limitations/implications: Use of a non-probability sampling strategy prevents the results being generalisable to the wider construction population. Several possible future research directions and methods are advised. These include qualitative investigations into the decision-making process around 4D BIM, and case study exploration of the consequences of 4D BIM innovation adoption.

Practical implications: Recommendations of how to facilitate the adoption of 4D BIM innovation are proposed, which identify the critical aspects of system compatibility and safe trialling of the innovation.

Originality/value: This paper reinforces 4D BIM as an innovation and records its actual UK industry adoption rate using an accepted diffusion research method. By focusing on UK industry-wide diffusion the work also stands apart from more typical research efforts that limit innovation diffusion exploration to individual organisations.

Keywords: 4D planning, Building Information Modelling (BIM), Construction planning, Innovation, Diffusion.

Citation: Gledson, B.J., and Greenwood, D. (2017) 'The adoption of 4D BIM in the UK Construction Industry - an Innovation Diffusion approach. *Engineering Construction and Architectural Management*, ISSN 0969-9988 (In press, accepted for publication in October 2016).

Much additional academic material has also been produced for peer-review and subsequently published in a range of formats. Some articles which have been directly informed by the study are currently in-press or pre-publication, whereas other outputs that have been indirectly shaped by the PhD study, also justify listing here.

Publications

- **Gledson, B.J.** and Phoenix, C. (2017) 'Which company attributes affect SME likeliness to innovate?' *Construction Innovation: Information, Process, Management*, 17(2), pp. 224-243.
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Participant ID	Online Survey ID	Sex	Age	Job Function	Job level	Date
Case study	-					
1		F		Company Director	Company Director level	26/07/12
2		M		Design Manager	Middle management level	31/07/12
3		M		QS	Middle management level	31/07/12
4		M		Construction Project Manager (single project)	Senior management level	31/07/12
5		M		Planner	Middle management level	31/07/12
6		M		Construction Project Manager (single project)	Senior management level	03/08/12
7		F		Planner	Middle management level	03/08/12
19		M			Middle management level	05/07/13
Online forum	-					
8		M		Other Consultant Professional	Company Director level	21/11/12
9		M		Other Consultant Professional	Senior management level	22/11/12
10		F		Business Development Company Director	Company Director level	22/11/12
11		M		Architect	Senior management level	22/11/12
12		M		Other Consultant Professional	Senior management level	22/11/12
13		M		Technical Specialist (i.e Planner; QS; Digital Engineer)	Senior management level	23/11/12
14		M		Software Vendor	Senior management level	23/11/12
15		M	25	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	26/11/12
16		M		Technical Specialist (i.e Planner; QS; Digital Engineer)		08/01/13
17		M		Other Consultant Professional		08/01/13
18		M		Other (Please Clarify Below)	Academic	11/01/13
Questionnaire 1	*136 Responses*					
20	206	M	30-34	Planner	Academic	04/07/13
21	207	F	40-44	Other (Please Clarify Below)	Academic	04/07/13
22	208	F	30-34	Design Manager	Middle management level	04/07/13
23	209	M	60-64	Other Consultant Professional	Senior management level	04/07/13
24	210	M	25-29	Planner	Middle management level	04/07/13
25	211	M	50-54	Planner	Middle management level	04/07/13
26	212	M	35-39	Planner	Middle management level	04/07/13
27	213	M	35-39	Design Manager	Middle management level	04/07/13
28	214	M	45-49	Planner	Senior management level	04/07/13
29	215	M	30-34	Other Consultant Professional	Middle management level	04/07/13
30	216	M	30-34	Planner	Middle management level	04/07/13
31	217	F	40-44	Planner	Middle management level	04/07/13
32	218	M	30-34	Planner	Middle management level	04/07/13
33	219	M	40-44	Planner	Middle management level	04/07/13
34	220	F	25-29	Design Manager	Senior management level	04/07/13
35	221	M	60-64	Planner	Middle management level	04/07/13
36	222	M	55-59	Consultant Project Manager (i.e. client side)	Senior management level	08/07/13
37	223	M	50-54	Company Director Level at Construction Firm	Company Director level	08/07/13
38	224	F	35-39	Planner	Senior management level	09/07/13
39	225	M	25-29	Other (Please Clarify Below)	Other	09/07/13
15	226	M	18-24	Planner	Middle management level	12/07/13
40	230	M	25-29	Site Manager	Middle management level	12/07/13
41	231	M	30-34	Company Director Level at Consultant Firm	Senior management level	12/07/13
42	232	M	45-49	Company Director Level at Construction Firm	Company Director level	12/07/13
43	235	M	35-39	Other (Please Clarify Below)	Senior management level	12/07/13
44	237	M	60-64	Other (Please Clarify Below)	Senior management level	12/07/13
45	238	M	50-54	Construction Project Manager (single project)	Middle management level	12/07/13
46	244	M	40-44	Company Director Level at Consultant Firm	Senior management level	12/07/13
47	246	M	35-39	Planner	Graduate management level	12/07/13
16	261	M	25-29	Planner	Middle management level	13/07/13
48	264	M	30-34	Quantity Surveyor	Senior management level	14/07/13
49	265	M	40-44	Architect	Company Director level	14/07/13

50	267	M	18-24	Architectural Technologist	Graduate management level	14/07/13
51	270	M	35-39	Other (Please Clarify Below)	Other	14/07/13
52	271	M	18-24	Other Consultant Professional	Other	18/07/13
53	272	M	55-59	Other (Please Clarify Below)	Company Director level	15/07/13
54	273	M	25-29	Architectural Technologist	Senior management level	15/07/13
55	275	M	30-34	Other (Please Clarify Below)	Middle management level	15/07/13
56	281	M	25-29	Planner	Middle management level	15/07/13
57	283	F	18-24	Site Engineer	Graduate management level	15/07/13
58	284	M	25-29	Site Manager	Middle management level	15/07/13
59	286	M	25-29	Graduate/Trainee Level	Graduate management level	15/07/13
60	287	M	30-34	Other (Please Clarify Below)	Senior management level	16/07/13
61	288	M	25-29	Architect	Graduate management level	16/07/13
62	290	M	40-44	Services Engineer	Academic	16/07/13
63	293	M	40-44	Construction Manager (across multiple projects)	Senior management level	17/07/13
64	294	M	35-39	Structural Engineer	Senior management level	17/07/13
65	297	M	25-29	Construction Project Manager (single project)	Middle management level	18/07/13
66	299	M	40-44	Planner	Middle management level	18/07/13
67	302	M	35-39	Planner	Middle management level	19/07/13
68	303	M	35-39	Architectural Technologist	Middle management level	19/07/13
69	306	M	60-64	Planner	Senior management level	20/07/13
70	309	M	18-24	Other (Please Clarify Below)	Middle management level	21/07/13
71	312	M	35-39	Other Consultant Professional	Senior management level	22/07/13
72	315	M	25-29	Design Manager	Middle management level	29/07/13
73	316	M	45-49	Other (Please Clarify Below)	Academic	30/07/13
74	319	F	under 18	Architect	Other	18/10/13
75	322	M	25-29	Consultant Project Manager (i.e. client side)	Graduate management level	05/08/13
76	323	M	25-29	Site Engineer	Graduate management level	19/10/13
77	325	M	30-34	Planner	Senior management level	06/08/13
78	329	M	45-49	Planner	Middle management level	09/08/13
79	330	M	25-29	Services Engineer	Graduate management level	09/08/13
80	333	F	18-24	Other Consultant Professional	Middle management level	18/10/13
81	335	M	35-39	Other Consultant Professional	Company Director level	11/08/13
82	336	M	25-29	Planner	Middle management level	18/10/13
83	339	M	25-29	Graduate/Trainee Level	Graduate management level	24/08/13
84	344	M	25-29	Planner	Senior management level	18/10/13
85	347	F	18-24	Other Consultant Professional	Graduate management level	18/10/13
86	348	M	25-29	Other Consultant Professional	Graduate management level	25/09/13
87	349	M	45-49	Other Design Professional	Middle management level	25/09/13
88	350	M	25-29	Design Manager	Middle management level	25/09/13
89	351	M	45-49	Architectural Technologist	Senior management level	25/09/13
90	352	M	35-39	Services Engineer	Senior management level	25/09/13
91	353	M	40-44	Construction Manager (across multiple projects)	Senior management level	25/09/13
92	354	F	30-34	Architect	Middle management level	25/09/13
93	355	M	30-34	Design Manager	Middle management level	25/09/13
94	356	M	45-49	Design Manager	Senior management level	25/09/13
95	357	M	40-44	Other Consultant Professional	Other	25/09/13
96	358	M	35-39	Quantity Surveyor	Senior management level	25/09/13
97	359	M	18-24	Planner	Graduate management level	07/10/13
98	360	M	30-34	Other (Please Clarify Below)	Academic	17/10/13
99	361	M	25-29	Planner	Middle management level	18/10/13
100	362	M	35-39	Planner	Middle management level	18/10/13
101	363	F	40-44	Planner	Company Director level	18/10/13
102	364	M	55-59	Planner	Middle management level	18/10/13
103	365	M	30-34	Planner	Middle management level	18/10/13
104	366	M	55-59	Consultant Project Manager (i.e. client side)	Senior management level	18/10/13

105	367	M	30-34	Planner	Middle management level	18/10/13
106	368	M	45-49	Planner	Middle management level	18/10/13
107	369	M	45-49	Planner	Senior management level	18/10/13
108	370	F	30-34	Planner	Middle management level	18/10/13
109	371	M	40-44	Company Director Level at Construction Firm	Company Director level	18/10/13
110	372	F	25-29	Other (Please Clarify Below)	Middle management level	18/10/13
111	373	M	30-34	Planner	Graduate management level	18/10/13
112	374	M	30-34	Design Manager	Middle management level	18/10/13
113	377	M	55-59	Planner	Senior management level	20/11/13
114	379	M	35-39	Planner	Senior management level	20/11/13
115	380	M	18-24	Planner	Academic	21/11/13
116	381	M	35-39	Planner	Graduate management level	21/11/13
117	382	M	35-39	Planner	Middle management level	21/11/13
118	383	M	45-49	Planner	Senior management level	21/11/13
119	384	M	45-49	Planner	Senior management level	21/11/13
120	385	M	50-54	Planner	Middle management level	21/11/13
121	386	M	40-44	Planner	Middle management level	21/11/13
122	387	F	25-29	Planner	Senior management level	21/11/13
123	388	M	35-39	Planner	Middle management level	21/11/13
124	389	M	30-34	Construction Project Manager (single project)	Academic	21/11/13
125	395	M	35-39	Planner	Senior management level	10/04/14
126	396	M	45-49	Planner	Middle management level	10/04/14
127	397	M	45-49	Planner	Middle management level	10/04/14
128	398	M	25-29	Planner	Middle management level	10/04/14
129	399	M	60-64	Planner	Middle management level	10/04/14
130	400	M	30-34	Planner	Middle management level	10/04/14
131	401	M	45-49	Planner	Middle management level	10/04/14
132	402	F	30-34	Planner	Middle management level	10/04/14
133	403	F	25-29	Planner	Middle management level	15/04/14
134	404	M	50-54	Company Director Level at Construction Firm	Company Director level	15/04/14
135	405	M	35-39	Planner	Middle management level	15/04/14
136	406	M	50-54	Construction Manager (across multiple projects)	Senior management level	15/04/14
137	407	M	40-44	Construction Manager (across multiple projects)	Senior management level	15/04/14
138	408	M	45-49	Planner	Middle management level	15/04/14
139	409	M	18-24	Planner	Graduate management level	15/04/14
140	411	M	45-49	Construction Project Manager (single1 project)	Middle management level	09/07/14
141	412	M	30-34	Design Manager	Middle management level	23/07/14
142	413	M	55-59	Planner	Middle management level	23/07/14
143	414	M	35-39	Design Manager	Middle management level	23/07/14
144	415	M	45-49	Planner	Senior management level	23/07/14
145	416	F	45-49	Planner	Middle management level	23/07/14
146	417	M	55-59	Planner	Senior management level	23/07/14
147	418	M	45-49	Consultant Project Manager (i.e. client side)	Senior management level	23/07/14
148	419	M	18-24	Design Manager	Graduate management level	23/07/14
149	420	F	40-44	Planner	Middle management level	23/07/14
150	421	M	55-59	Company Company Director Level at Consultant Firm	Company Director level	23/07/14
151	422	M	45-49	Planner	Senior management level	23/07/14
152	423	M	45-49	Planner	Senior management level	23/07/14
153	424	M	60-64	Planner	Senior management level	23/07/14
Questionnaire 2	***97 Responses[1]***					
154	1283	M	30	Management Professional	Upper management level	14/04/15
155	1286	M	28	Management Professional	Lower management	15/04/15

1 The datapoints for the 97 responses for questionnaire 2 are numbered sequentially. For example, Online Survey ID 1283 is datapoint 1, and Online Survey ID 1431 is datapoint 97

156	1287	M	31	Management Professional	Middle management level	15/04/15
157	1288	M	30	Management Professional	Middle management level	15/04/15
135	1289	M	38	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	15/04/15
53	1290	M	59	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level	15/04/15
41	1291	M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	15/04/15
15	1292	M	25	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	16/04/15
158	1293	F	26	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	16/04/15
113	1294	M	58	Management Professional	Upper management level	16/04/15
159	1295	M	37	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	16/04/15
160	1296	F	44	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	16/04/15
161	1297	M	60	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level	16/04/15
162	1300	M	35	Design Professional	Lower management	16/04/15
163	1301	M	47	Management Professional	Middle management level	16/04/15
164	1304	M	42	Management Professional	Middle management level	16/04/15
165	1306	M	50	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	17/04/15
166	1307	M	34	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	17/04/15
167	1308	M	50	Management Professional	Upper management level	17/04/15
168	1309	M	44	Management Professional	Middle management level	17/04/15
169	1310	M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	17/04/15
170	1312	M	43	Management Professional	Upper management level	17/04/15
171	1314	M	60	Management Professional	Middle management level	17/04/15
172	1316	M	27	Management Professional	Lower management	17/04/15
173	1317	M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	17/04/15
174	1318	M	42	Management Professional	Upper management level	17/04/15
175	1320	M	39	Management Professional	Upper management level	17/04/15
176	1321	M	44	Design Professional	Upper management level	17/04/15
177	1322	M	31	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	18/04/15
178	1324	M	25	Management Professional	Middle management level	18/04/15
179	1327	M	40	Management Professional	Middle management level	19/04/15
180	1329	M	32	Management Professional	Lower management	19/04/15
181	1330	M	44	Management Professional	Middle management level	19/04/15
182	1335	M	31	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	20/04/15
183	1339	F	38	Management Professional	Middle management level	20/04/15
184	1340	M	56	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	20/04/15
185	1343	M	39	Management Professional	Lower management	21/04/15
186	1345	M	44	Management Professional	Middle management level	21/04/15
187	1346	M	50	Management Professional	Lower management	22/04/15
188	1347	M	59	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	24/04/15
189	1349	M	48	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level	23/04/15
190	1350	M	35	Management Professional	Upper management level	23/04/15
191	1351	F	27	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	24/04/15
192	1352	M	42	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	24/04/15
193	1353	M	38	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	24/04/15
194	1354	M	27	Management Professional	Middle management level	24/04/15
195	1355	M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	24/04/15
123	1356	M	40	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	24/04/15
196	1357	M	31	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	25/04/15
197	1358	M	47	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	25/04/15
198	1359	M	28	Management Professional	Lower management	25/04/15
199	1360	M	47	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	25/04/15
200	1361	M	41	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	25/04/15
201	1363	M	41	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	26/04/15
202	1364	M	61	Design Professional	Middle management level	26/04/15
203	1365	M	34	Management Professional	Middle management level	26/04/15
204	1367	M	33	Management Professional	Lower management	27/04/15

205	1368	F	41	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	27/04/15
206	1369	M	50	Management Professional	Upper management level	27/04/15
207	1370	M	43	Management Professional	Upper management level	28/04/15
208	1372	M	36	Management Professional	Middle management level	07/05/15
209	1374	M	43	Management Professional	Lower management	07/05/15
210	1375	M	25	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	07/05/15
211	1376	M	50	Management Professional	Upper management level	07/05/15
212	1381	F	53	Management Professional	Middle management level	08/05/15
213	1383	M	29	Management Professional	Middle management level	08/05/15
214	1384	M	68	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level	08/05/15
215	1387	M	35	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	09/05/15
216	1392	F	53	Management Professional	Upper management level	10/05/15
217	1395	M	37	Management Professional	Middle management level	11/05/15
218	1397	F	28	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	11/05/15
219	1399	M	39	Management Professional	Upper management level	12/05/15
220	1401	M	34	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	15/05/15
221	1404	F	35	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	19/05/15
222	1405	F	27	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	20/05/15
223	1406	M	35	Management Professional	Middle management level	21/05/15
224	1407	M	38	Management Professional	Upper management level	23/05/15
225	1408	M	39	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	30/05/15
226	1409	M	22	Design Professional	Lower management	05/06/15
227	1410	M	35	Management Professional	Upper management level	09/06/15
228	1414	M	23	Design Professional	Lower management	04/07/15
229	1415	M	52	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	04/07/15
230	1416	M	48	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	04/07/15
231	1417	M	55	Management Professional	Upper management level	04/07/15
232	1418	M	38	Management Professional	Upper management level	06/07/15
233	1419	M	53	Management Professional	Middle management level	06/07/15
234	1420	M	60	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	06/07/15
235	1421	M	39	Management Professional	Upper management level	06/07/15
236	1422	M	30	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	06/07/15
237	1423	M	42	Management Professional	Lower management	07/07/15
238	1424	F	32	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	07/07/15
239	1425	M	60	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level	07/07/15
240	1426	M	25	Management Professional	Lower management	07/07/15
241	1427	M	39	Management Professional	Upper management level	07/07/15
242	1429	M	28	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	09/07/15
243	1430	M	61	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	09/07/15
244	1431	M	56	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	09/07/15
SS Interviews	-					
210		M	25	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	11/05/15
245		M	37	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	12/05/15
100		M	35-39	Planner	Middle management level	14/05/15
203		M	34	Management Professional	Middle management level	26/04/15
195		M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	15/05/15
193		M	38	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	15/05/15
41		M	33	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	18/05/15
189		M	48	Technical Specialist (i.e Planner; QS; Digital Engineer)	Upper management level	20/05/15
15		M	25	Technical Specialist (i.e Planner; QS; Digital Engineer)	Lower management	21/05/15
123		M	40	Technical Specialist (i.e Planner; QS; Digital Engineer)	Middle management level	12/06/15
231		M	55	Management Professional	Upper management level	11/07/15
241		M	39	Management Professional	Upper management level	16/07/15
246		M		Planner		21/07/15

D-1. Research Instrument 1: Case Study Interview Guide

1) What were your preconceived ideas or perceptions, relating to BIM (*in terms of fears, concerns, hopes*)

2) Are there barriers to the implementation of BIM within contracting organisations?
    - *What are they?*

3) Are there Benefits to the implementation of BIM within contracting organisations?
    - *What are they?*
    - *What benefits your role?*
    - *What benefits are there in comparison to previous projects?*
    - *How can these benefits be measured (in order to demonstrate to management)?*

4) Can you give any specific examples of where using BIM solved or helped you to solve a key issue of problem?

5) What is your perception of the necessary elements that contracting organisations need to have in place for the implementation and use of BIM?
    - *What needs to be in place?*
    - *What has been put in place?*

6) Discuss the impacts of external factors upon the implementation programme:
    - Economy
    - Government targets
    - Any others

7) What are your experiences of the implementation programme? (*personal experiences or observations on others experiences*)

8) What are the current outcomes of any/the implementation programme? (*impact at industry level; organisational level; project level*)

9) What about the future? – BIM Maturity levels, IFC’s

D-2. Research Instrument 2: Questionnaire - Planning and controlling construction projects using BIM and Virtual Construction

Dear Respondent,

I am a Construction Management lecturer who previously worked in industry as a construction planner. I am currently undertaking a PhD research project for Northumbria University relating to the planning and controlling of construction projects using BIM and Virtual Construction. If you have an interest in either BIM or Virtual Construction or any insight into this topic I would be extremely grateful if you would consider spending 12 minutes of your valuable time to complete this questionnaire. There is no personal or commercially sensitive information required and the information you provide will remain anonymous. You can save your survey at any time and can come back to it. At the bottom of each page is the save and continue later option. If you supply an email address to save your progress, a unique link will be emailed to you that will allow you to return to your survey where you left off. This means of data collection is part of a wider method that also involves the use of interviews and case study research. If you would be interested in knowing more about the project, including details of how you could participate further you can make contact with me via my email barry.gledson@northumbria.ac.uk or LinkedIn profile page http://uk.linkedin.com/pub/barry-gledson/1a/a1/34 and I will be happy to contact you to discuss this and answer any questions you may have. The target audience for this study is all construction disciplines working for contracting organisations in any tier of the UK construction Industry. For those who are not really aware of BIM or Virtual Construction this survey has been designed to take this into consideration, and will hopefully raise your awareness and I still would greatly value your opinions so please go ahead and attempt the questionnaire.

Many thanks

Barry Gledson

I understand the information I give will remain anonymous and confidential?

[ ] Yes

[ ] No

I have been briefed about this research and its purpose and agree to participate?

[ ] Yes

[ ] No

Your Profile

1) Gender

[ ] Male

[ ] Female

2) Age

[ ] under 18

[ ] 18-24

[ ] 25-29

[ ] 30-34

[ ] 35-39

[ ] 40-44

[ ] 45-49

[ ] 50-54

[ ] 55-59

[ ] 60-64

[ ] 65+

3) Current Job Function

Please tick role that most closely aligns with your job function

[ ] Director Level at Construction Firm

[ ] Construction Manager/Contracts Manager (responsibility for overseeing multiple projects)

[ ] Construction Project Manager (i.e. with overall responsibility for running 1 project)

[ ] Planner (any level - senior, assistant etc)

[ ] Design Manager (any level - senior, assistant etc)

[ ] Quantity Surveyor (any level - senior, assistant etc)

[ ] Site Manager (site based working under a construction project manager on a project)

[ ] Specialist at contracting firm (such as Temporary Works Coordinator; M&E manager etc; H&S manager)

[ ] Site Engineer

[ ] Graduate/Trainee Level (may be on a company training scheme)

[ ] Administrative/Support personnel

[ ] Director Level at Consultant Firm

[ ] Consultant Project Manager (i.e. client side)

[ ] Architect

[ ] Architectural Technologist

[ ] Structural Engineer

[ ] Services Engineer

[ ] Other Design Professional

[ ] Other Consultant Professional

[ ] Other (Please Clarify Below)

4) Other (Job function not listed above)

____

5) What best describes your job level?

[ ] Director level

[ ] Senior management level

[ ] Middle management level

[ ] Graduate management level

[ ] Academic

[ ] Other

6) Number of years' experience in the construction industry

[ ] under 1 year

[ ] 1-5

[ ] 6-10

[ ] 11-20

[ ] 21-30

[ ] 31-40

[ ] 41+

7) If you wish, you can add a brief statement clarifying experience in construction industry

For example, if you are listed as a Director then you may want to expand with "was previously a site manager for 20 years"

____

8) Company Size (in employees)

[ ] 1-49 employees (classified as small sized company)

[ ] 50-249 employees (classified as a medium sized company)

[ ] 250+ employees (classified as a large company)

9) Please identify the usual annual turnover of your company (If this fluctuates significantly - try to identify an average amount taken over the past 5 years)

[ ] Less than £1 million

[ ] Up to £5 million

[ ] Up to £10 million

[ ] Up to £25 million

[ ] Up to £50 million

[ ] Up to £100 million

[ ] Up to £250 million

[ ] Up to £500 million

[ ] Over £500 million

[ ] N/A

10) From the options available, what would your preferred procurement strategy be on a project?

[ ] Traditional

[ ] Design & Build (Novated design team)

[ ] Design & Build (In house design team)

[ ] Construction Management

[ ] Management Contracting

[ ] PFI

[ ] Other

11) If you responded with 'other' please clarify

____

____

____

____

12) How many projects have you been involved in personally (in any capacity) that has used BIM in some capacity

[ ] 0

[ ] 1-5

[ ] 6-10

[ ] 11-15

[ ] 16-20

[ ] 21-25

[ ] 26-30

[ ] 31-35

[ ] 36-40

[ ] 41-45

[ ] 46-50

[ ] 50+

13) Approximate Total Value (in £ millions) of the BIM projects you have had some capacity working on?

[ ] Have not worked on any Project using BIM in any capacity

[ ] Project(s) of up to £4 Million

[ ] Project(s) of up to £10 Million

[ ] Project(s) of up to £15 Million

[ ] Project(s) of up to £20 Million

[ ] Project(s) of up to £25 Million

[ ] Project(s) of up to £30 Million

[ ] Project(s) of up to £35 Million

[ ] Project(s) of up to £40 Million

[ ] Project(s) of up to £45 Million

[ ] Project(s) of up to £50 Million

[ ] Project(s) of up to £55 Million

[ ] Project(s) of up to £60 Million

[ ] Project(s) of up to £65 Million

[ ] Project(s) of up to £70 Million

[ ] Project(s) of up to £75 Million

[ ] Project(s) of up to £80 Million

[ ] Project(s) of up to £85 Million

[ ] Project(s) of up to £90 Million

[ ] Project(s) of up to £95 Million

[ ] Project(s) of up to £100 Million

[ ] Project(s) worth over £100 Million

BIM Implementation

14) In your opinion, which party is best placed to manage the BIM model on a project?

[ ] The lead design consultant is best placed (e.g. Architect)

[ ] The contractor is best placed

[ ] Clients project manager or representative

[ ] It depends on the procurement route

[ ] Other

15) Does your company have plans to implement BIM?

[ ] Has already commenced implementing BIM

[ ] Is planning to implement BIM

[ ] Is not planning to implement BIM

[ ] Unsure

16)

Please review the above BIM Maturity diagram. In the official government BIM stragegy of May 2011, there is a target of 2016 for all Government projects of a value of £5m+ to be undertaken by contractors who have attained Level 2. Do you think that this is realistic?

[ ] Yes

[ ] No

17) Where (on the diagram) would you assess the current BIM maturity level of your company?

[ ] Level 0

[ ] Level 1

[ ] Level 2

[ ] Level 3

18) In terms of BIM implementation would you agree or disagree that your company has:

	Agree	Disagree
A clear methodology	[ ]	[ ]
A well defined strategy	[ ]	[ ]
Clear direction from upper management	[ ]	[ ]
High commitment from upper management	[ ]	[ ]
A special task force driving implementation	[ ]	[ ]
Key personnel (champions) driving implementation	[ ]	[ ]
Adequate knowledge of BIM concepts by most staff at your level	[ ]	[ ]
Adequate knowledge of implementation program by most staff at your level	[ ]	[ ]
An Effective company communication system	[ ]	[ ]
Trial projects	[ ]	[ ]
Communicated lessons learned throughout the company	[ ]	[ ]

19) What BIM maturity would you anticipate your company being at in 2016

[ ] Level 0

[ ] Level 1

[ ] Level 2

[ ] Level 3

20) Here is a list of external barriers that affect industry wide BIM implementation. Please order these barriers from 1-8 with 1 being the largest barrier and 8 being the smallest barrier.

________The nature of the industry itself i.e. Fragmentation & subcontracting

________The structure of procurement & contracts

________A lack of adequate BIM awareness & understanding

________Culture & human attitudinal issues

________Time & commercial pressures

________Lack of leadership

________Issues around education and training

________Lack of proof of performance from measurement systems

21) If you think that there are other major external barriers that are not listed and would like to identify these, please use this space below

____

____

____

____

22) Here is a list of internal factors that affects BIM implementation. Please rank (highest to lowest) the following internal challenges to BIM implementation within your company with 1 being the largest challenge and 3 being the smallest challenge.

________Issues with people

________Issues with process

________Issues with technology

23) Please rank in order of importance the following benefits of BIM from your perspective? Please order these benefits from 1-3 with 1 being the largest benefit and 3 being the smallest benefit.

________Improvements in Product modelling and analysis

________Improvements in Process modelling and analysis

________Improvements in Communication and collaboration

For the purposes of this survey, we can take mid 2008 to be the point when the global recession of 2008-2012 started to impact upon the UK economy

24) Was your company implementing BIM working practices before or after mid 2008?

[ ] Before mid 2008

[ ] After mid 2008

[ ] My company is not currently attempting to implement BIM

25) How do you believe that this recession has impacted upon any BIM implementation efforts that your company has tried to pursue

[ ] My company is not currently attempting to implement BIM working practices

[ ] My company was trying to implement BIM before this date and I believe the recession has negatively affected the implementation programme

[ ] My company was trying to implement BIM before this date and I believe the recession has helped the implementation programme

[ ] My company did not start trying to implement BIM until after the recession commenced and I believe it has negatively affected the implementation programme

[ ] My company did not start trying to implement BIM until after the recession commenced and I believe it has helped the implementation programme

[ ] My company did not start trying to implement BIM until after the recession commenced and I am not sure how the recession has impacted the programme

26) Please expand if you want to add any opinions on your answer here

____

____

____

____

4D Planning, Virtual Construction and the Virtual Construction Environment

27) Has your company used Virtual Construction before?

[ ] Yes the company has used elements of virtual construction on live projects

[ ] Yes but not on live projects. The company has investigated virtual construction internally

[ ] No the company has not used elements of virtual construction in any capacity

[ ] Unsure/not aware

28) If so, can you provide information on if your company has used Virtual Construction to help in any of the following areas:

	Yes	No
To win work	[ ]	[ ]
To interrogate design	[ ]	[ ]
To communicate project timescales	[ ]	[ ]
To plan construction methods	[ ]	[ ]
To identify scale and working space	[ ]	[ ]

To identify hazards	[ ]	[ ]
To assist with safety planning	[ ]	[ ]
To aid planning for resource management	[ ]	[ ]

29) Has your company used the Virtual Construction Environment for site layout planning for any of the following elements

	Yes	No
Site Security	[ ]	[ ]
Pedestrian & Traffic Management Planning	[ ]	[ ]
Site logistics	[ ]	[ ]
Major plant	[ ]	[ ]
Temporary Works	[ ]	[ ]
Welfare facilities	[ ]	[ ]
Materials delivery and storage	[ ]	[ ]

30) Please indicate the level of value that you believe 4D planning would add to your business

No Value

[ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

High Value

31) Please score each of the following elements in terms of how 4D Planning may offer an improvement on traditional processes:

A = Traditional planning process are better than 4D planning

B = Traditional process and 4D Planning processes are equal in this respect

C = 4D Planning processes offer a small improvement in this respect

D = 4D Planning processes offer a significant improvement in this respect

	A	B	C	D
Work winning	[ ]	[ ]	[ ]	[ ]
Planning the construction process	[ ]	[ ]	[ ]	[ ]
Visualising the construction process	[ ]	[ ]	[ ]	[ ]
Understanding the construction process	[ ]	[ ]	[ ]	[ ]

Validating the time schedule	[ ]	[ ]	[ ]	[ ]
Detailed planning such as location based planning	[ ]	[ ]	[ ]	[ ]
Progress reporting, such as reviewing planned v actual data	[ ]	[ ]	[ ]	[ ]

32) Specifically focusing on the construction planning process itself, please review each of the following elements in terms of how new methods of working (BIM/VC/4D) compare against traditional methods of working regarding the planning process:

A = Traditional methods are better than new methods

B = Traditional methods and new methods are equal in this respect

C = New methods offer a small improvement in this respect

D = New methods offer a significant improvement in this respect

	A	B	C	D
Gathering information	[ ]	[ ]	[ ]	[ ]
Identifying activities	[ ]	[ ]	[ ]	[ ]
Assessing durations	[ ]	[ ]	[ ]	[ ]
Logical relationships	[ ]	[ ]	[ ]	[ ]
Sequence	[ ]	[ ]	[ ]	[ ]
Project Timescales	[ ]	[ ]	[ ]	[ ]
Communicating the plan	[ ]	[ ]	[ ]	[ ]

33) In terms of method planning of construction work, to what extent has your company used Virtual Construction (select all that apply):

[ ] Have not used Virtual Construction in method planning

[ ] Used to identify construction methods

[ ] Used to assess construction methods

[ ] Used to plan construction methods

[ ] Used to communicate construction methods

[ ] Used to manage construction methods

34) In terms of time scheduling of construction work, to what extent has your company used Virtual Construction (select all that apply):

[ ] Have not used Virtual Construction in time scheduling of construction work

[ ] Used to identify construction timescales

[ ] Used to assess construction timescales

[ ] Used to plan construction timescales

[ ] Used to communicate construction timescales

[ ] Used to manage construction timescales

35) Please expand if you want to add any extra information regarding any of your answers in this section of the questionnaire here

____

____

____

____

____

(untitled)

36) If you would you be willing to participate in a follow up interview with myself in order to further assist in this study (which would take between 30 minutes -1 hour) please leave your name and a contact detail such as work email or telephone number below.

Name:: ____

Work Email:: ____

Work Telephone:: ____

____

Thank You!

____

D-3. Research Instrument 3: Questionnaire - Investigating the diffusion of 4D BIM innovation

Dear Respondent,

I am a Construction Project Management lecturer who previously worked in industry as a construction planner. I am currently undertaking PhD research relating to 4D BIM for the planning of construction projects. If you have an interest or any insight into this topic I would be extremely grateful if you would consider spending 10-15 minutes of your valuable time to complete this questionnaire. There is no commercially sensitive information required and the information you provide will remain anonymous. You can save your survey at any time and can come back to it. At the top of each page is an option that will allow you to save and continue later. If you supply an email address to save your progress, a unique link will be emailed to you that will allow you to return to your survey where you left off. This means of data collection is part of a wider method that also involves the use of interviews and case study research. If you would be interested in knowing more about the project, including details of how you could participate further you can make contact with me via my email barry.gledson@northumbria.ac.uk or LinkedIn profile page http://uk.linkedin.com/pub/barry-gledson/1a/a1/34 and I will be happy to contact you to discuss this and answer any questions you may have. The target audience for this study is all construction disciplines working for or with contracting organisations delivering construction projects across any tier of the UK construction Industry. For those who are not really aware of 4D BIM this survey has been designed to take this into consideration, and will hopefully raise your awareness and I still would greatly value your opinions so please go ahead and attempt the questionnaire. For certain key questions you will need to enter the name of a year as a response. One such question for this study is "*In which year was your company established?*" It would therefore be useful if you have this information to hand before starting the survey. Another key question is "*In which year did you first become aware of 4D BIM*" which requires you to recall this information accurately. For questions such as these, please enter the year as a 4 digit number i.e. 2010. You can use the 'back' button to correct your answers at any time in the survey. Finally whilst many of the questions require you to select from pre-arranged response options, there is an opportunity at the end of the questionnaire in case you wish to provide any additional comments or expand upon any of your previous answers.

Many thanks

Barry Gledson

I understand the information I give will remain anonymous and confidential?

[ ] Yes

[ ] No

I have been briefed about this research and its purpose and agree to participate?

[ ] Yes

[ ] No

____

Your Profile

1) Gender

[ ] Male

[ ] Female

2) Age

____

3) Highest level of education acheived

[ ] School leaver (less than 6th form)

[ ] School leaver (completed 6th form)

[ ] Further Education - Achieved college qualification(s)

[ ] Higher Education - Achieved university undergraduate degree(s)

[ ] Higher Education - Achieved post-graduate qualification(s)

4) Total Household Income (in £GBP)

[ ] Less than 25k

[ ] 25,000 to 34,999

[ ] 35,000 to 49,999

[ ] 50,000 to 74,999

[ ] 75,000 to 99,999

[ ] 100,000+

5) Current Job Function

Please select option that most closely aligns with your job function

[ ] Management Professional (i.e. the primary function of your job role involves the direct management of people or processes. Your management responsibilities may be at multi-project, individual project or individual site based levels)

[ ] Design Professional (i.e. the primary function of your job role requires you to produce design information.

[ ] Technical Specialist (i.e. the primary function of your job role is not the direct management of people, but management of a process or providing specialist technical advice or output. Examples include Planner/Design Manager/QS.

6) What best describes your job level?

[ ] Upper management level - responsible for long term strategic direction of company.

[ ] Middle management level - responsible for tactical management decisions in order to achieve strategic company targets.

[ ] Lower management - direct responsibility for day to day running of operations.

7) Number of years you have worked in the construction industry?

____

8) In which year did you start working in the construction industry? (Remember please enter the year as a 4 digit number)

____

9) Company Size (in employees)

[ ] 1-49 employees (classified as small sized company)

[ ] 50-249 employees (classified as a medium sized company)

[ ] 250+ employees (classified as a large company)

10) In which year was your company established?

____

11) Please review the NBS (2014) description of BIM Levels. Please identify below where you assess the current BIM maturity level of your company to be.

Level 0 - *"… effectively means no collaboration. 2D CAD drafting only is utilised, mainly for Production Information. Output and distribution is via paper or electronic prints, or a mixture of both … "*

Level 1 - *"… typically comprises a mixture of 3D CAD for concept work, and 2D for drafting of statutory approval documentation and Production Information. CAD standards are managed to BS 1192:2007, and electronic sharing of data is carried out from a common data environment (CDE), often managed by the contractor. There is no collaboration between different disciplines – each publishes and maintains its own data."*

Level 2 - *"…is distinguished by collaborative working – all parties use their own 3D CAD models, but not necessarily working on a single, shared model. The collaboration comes in the form of how the information is exchanged between different parties – and is the crucial aspect of this level. Design information is shared through a common file format, which enables any organisation to be able to combine that data with their own in order to make a federated BIM model, and to carry out interrogative checks on it. Hence any CAD software that each party used must be capable of exporting to one of the common file formats such as IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange). This is the method of working that has been set as a minimum target by the UK government for all work on public-sector work, by 2016.*

Level 3 - *"… represents full collaboration between all disciplines by means of using a single, shared project model which is held in a centralised repository. All parties can access and modify that same model, and the benefit is that it removes the final layer of risk for conflicting information …"*

[ ] Level 0

[ ] Level 1

[ ] Level 2

[ ] Level 3

Perceived Attributes of 4D BIM Innovation

12) In which year did you first become aware of 4D BIM? (Remember please enter the year as a 4 digit number)

____

13) What was your first impression of 4D BIM

[ ] Very unfavourable

[ ] Unfavourable

[ ] Neutral

[ ] Favourable

[ ] Very favourable

14) Do you currently use 4D BIM in your construction planning practices?

[ ] Yes

[ ] No

15) In which year did you adopt 4D BIM innovation in your construction planning practices for the first time? (Remember - please enter the year as a 4 digit number)

____

16) Are you aware of anyone in your organisation who currently uses 4D BIM in their construction planning practices?

[ ] Yes

[ ] No

17) In which year did these persons in your organisation adopt 4D BIM innovation for the first time? (Remember - please enter the year as a 4 digit number)

____

18) Please indicate the level of value that you now believe 4D BIM adds or would add to your business

No Value

[ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

High Value

Assessing the relative advantages of 4D BIM against functions of construction planning

19) In general, the use of 4D BIM would be more effective in work winning activities than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

20) In general, the use of 4D BIM would be more effective for interrogating design than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

21) In general, the use of 4D BIM would be more effective in planning construction methods than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

22) In general, the use of 4D BIM would be more effective in visualising the construction process than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

23) In general, the use of 4D BIM would be more effective in facilitating understanding of the construction process than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

24) In general, the use of 4D BIM would be more effective in validating the time schedule than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

25) In general, the use of 4D BIM would be more effective in location based planning than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

26) In general, the use of 4D BIM would be more effective for progress reporting than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

27) In general, the use of 4D BIM would be more effective for site layout planning (positions) than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

28) In general, the use of 4D BIM would be more effective for logistics planning (movements) than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

29) In general, the use of 4D BIM would be more effective for communicating working space than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

30) In general, the use of 4D BIM would be more effective in safety planning than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

---

Assessing the relative advantages of 4D BIM against stages of the construction planning process

31) In general, the use of 4D BIM would be more effective for gathering information than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

32) In general, the use of 4D BIM would be more effective for identifying activities than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

33) In general, the use of 4D BIM would be more effective for assessing activity durations than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

34) In general, the use of 4D BIM would be more effective for planning the logical dependencies between activities than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

35) In general, the use of 4D BIM would be more effective for planning the construction sequence than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

36) In general, the use of 4D BIM would be more effective for communicating the construction plan than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

37) In general, the use of 4D BIM would be more effective for communicating project timescales than our current practices

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

---

Issues of compatibility, complexity, trialability and observability

38) Compatibility: The use of 4D BIM is compatible with our current practice of construction planning

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

39) Complexity: 4D BIM methods would be difficult to learn

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

40) Complexity: 4D BIM methods would be difficult for planners to understand

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

41) Complexity: The training required in order to learn 4D BIM methods would be complicated

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

42) Trialability: 4D BIM methods would have to be experimented with before using to plan real construction work

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

43) Observability: It is easy to see the impact that 4D BIM has on construction planning effectiveness

[ ] Strongly disagree [ ] Disagree [ ] Neutral [ ] Agree [ ] Strongly agree

Type of Innovation-Decision

44) Please confirm if a decision has been made to adopt or reject the use of 4D BIM for the planning of construction work

[ ] Adopt

[ ] Reject

[ ] Undecided/no decision made

45) If possible, please explain which type of decision was made (or would be made) to adopt 4D BIM

[ ] Optional Decision

[ ] Collective Decision

[ ] Authority Decision

46) If possible, please explain which type of decision was made to reject 4D BIM Innovation

[ ] Optional Decision

[ ] Collective Decision

[ ] Authority Decision

47) Communication Channels: Please select your preference for obtaining information about 4D BIM

[ ] External Sources, i.e.: Mass media including websites, journals, magazines; government

[ ] Internal sources i.e.: Colleagues, peers, workmates or interpersonal networks

48) Communication Channels: Which of the following has had/would have the biggest impact on your own personal decision to adopt or reject the use of 4D BIM

[ ] External Influences, i.e.: Mass media including websites, journals, magazines; or government

[ ] Internal influences, i.e.: Colleagues, peers, workmates or interpersonal networks

49) Please expand here if you want to add any extra information such as discussing the consequences of a decision to adopt 4D BIM, or if you want to expand on any of your previous answers.

____

____

____

____

____

(untitled)

50) If you would you be willing to participate in a follow up interview with myself in order to further assist in this study (which would take between 30 minutes - 1 hour) please leave your name and a contact detail such as work email or telephone number below.

Name:: ____

Work Email:: ____

Work Telephone:: ____

____

Thank You!

____

D-4. Research Instrument 4: Semi-Structured Interview Guide

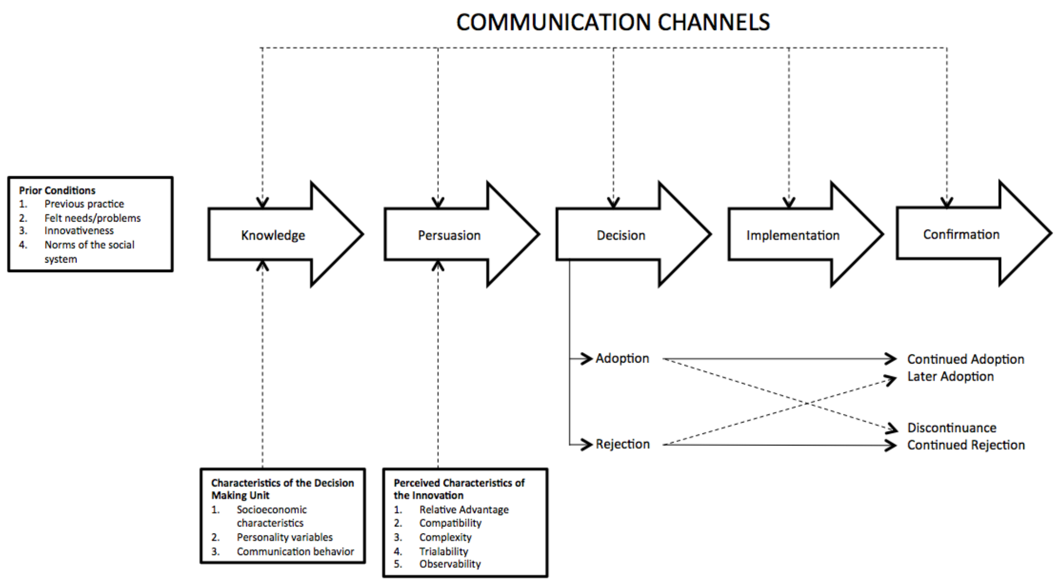
The first few questions 1-3 focus on innovations and the construction industry in general. An innovation is defined as "*an idea, practice or object that is perceived as new by an individual or other unit of adoption*", after that a few questions focus on specific innovations of BIM and 4D BIM. The last question relates to construction project time predictability.

1) What is your assessment of the level of innovation in the construction industry?
2) Does the way that the industry is structured affect the levels of construction innovation?
3) How are industry innovations best implemented?

About BIM in general:

4) Has BIM impacted upon the quality of production information?
5) Has BIM impacted upon the planning of construction work?

The rest of the question focus just on 4D BIM. First please review the below model and text describing the 5 stages of the Innovation decision process.



The innovation-decision-process is the process through which an individual (or other decision making unit) passes from first knowledge of an innovation to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision.

6) You identified in the questionnaire when you were first aware of 4D BIM and when you first used it (the knowledge (I) and decision (III) stages respectively). I'd like to explore some further aspects of this 'innovation decision' period in line with the above model: For example, (I) what was your initial knowledge of 4D BIM; (II) what persuaded you to consider the use of 4D BIM; (III) what initial decision was made after first use - adoption or rejection; (IV) any issues around the implementation - when it was put into actual practice; and (V) has any confirmation occurred to reinforce the adoption / rejection decision made.

7) On the questionnaire you have already identified the impact of communication channels upon your use of 4D BIM. As a reminder these communication channels are external (such as mass media - internet, literature etc.) and internal (such as interpersonal - face to face exchanges between two or more individuals) communication channels. Could you expand further on your original answers?

8) Key persons involved in any innovation diffusion effort are opinion leaders and change agents. An opinion leader is someone internal to your company or network who provides information and advice about innovations often in an informal role. A 'change agent' is someone external from your company or network who acts as a link between the generators of an innovation and any potential adopters of an innovation. In this instance a change agent may be someone who acted as a link in-between government task force or software vendors and yourself. Can you recall any particular interaction with individuals who fit these descriptions, and how this interaction impacted upon the innovation-decision process?

9) There are always consequences (changes) that occur as a result of adoption or rejection of an innovation I'd like to explore these. Can you tell me of any (I) desirable or undesirable consequences (II) direct or indirect consequences and (III) anticipated or unanticipated consequences of 4D BIM innovation?

10) The government has a target for 2025 that all construction projects are to be delivered 50% faster (from inception to completion) than the industry 2013 performance, where only 45% of projects were delivered on time or better. Do you think the use of 4D BIM can help improve the time predictability of construction projects? And if so how?

E-1. Research Instrument 1: Case Study Interview Guide

This research instrument helped partially address **Research Objective 1** '*Examine classic innovation diffusion theory and its applicability to the construction industry*', as well as **Research Objective 3** '*Examine, through the collection of empirical data, the development of* [BIM, and] *4D BIM in the UK construction industry*'. In relation to RO1, and as identified in Chapter 4, several of the questions were related to Rogers (2003) original innovation-decision process model, as clarified below.

Table E-1: Theoretical underpinning of key questions in Research Instrument 1.

NR.	Question theme	Relevant literature.
1	Perceptions related to BIM	Relates to the 'Knowledge' and 'Persuasion' stages of Rogers (2003) innovation-decision process model. Also see Rekola, Kojima and Mäkeläinen (2010); Eastman et al., (2011); Sebastian (2011); BIWG (2011); Crotty (2012).
2	Barriers to the BIM implementation within contracting organisations.	Relates to the 'Persuasion' stages of Rogers (2003) innovation-decision process model. Also see Venkatesh *et al*., (2003); Peansupap and Walker (2006); Bew and Underwood (2009); Dawood (2010); Li, Lu and Huang (2009); Sacks *et al*., (2010); Owen, *et al*., (2010); Hjelseth (2010); Eastman *et al*., (2011); Sebastian (2011); BIWG (2011); Crotty (2012); Emmitt and Ruikar (2013).
3	Benefits to BIM implementation within contracting organisations.	Relates to the 'Persuasion' stage of Rogers (2003) innovation-decision process model. Also see Wang (2002); Waly and Thabet (2003); Huang *et al*., (2007; 2009); Li *et al*., (2008); Rekola *et al*., (2010); Sebastian (2011); Eastman *et al*., (2011); Crotty (2012); Succar, Sher and Williams (2012); Davies and Harty, (2013a); Poirier *et al*., (2015).
4	Examples where BIM helped in work.	Relates to the 'Implementation' stage of Rogers (2003) innovation-decision process model.
5	Necessary elements needed by contracting organisations for the implementation and use of BIM.	Relate to the 'prior conditions' which Rogers (2003) identifies as impacting upon the innovation-decision process.
6	Impacts of external factors upon implementation.	Relate to the 'prior conditions' which Rogers (2003) identifies as impacting upon the innovation-decision process.
7	Experiences of implementation.	Relates to the 'Confirmation' stage of Rogers (2003) innovation-decision process model.

8	Outcomes of implementation.	Relates to the 'Confirmation' stage of Rogers (2003) innovation-decision process model.
9	What about the future?	-

E-2. Research Instrument 2: Questionnaire - Planning and controlling construction projects using BIM and Virtual Construction

This research instrument was designed to address **Research Objective 3** and '*examine, the development of 4D BIM adoption in the UK construction industry'*. The survey also partially meets some of the sub-objectives of **Research Objective 4** by investigating the diffusion of 4D BIM innovation within UK planning practice, specifically: (4.1) '*explore and explain construction planning functions that 4D BIM is principally being used for'*; and (4.2) '*explore and explain the extent of use of 4D BIM innovation*'.

Table E-2: Theoretical underpinning of key questions in Research Instrument 2.

NR.	Question theme	Relevant literature.
1-13	Demographic type questions	-
14, 15-17, 19	BIM implementation plans.	Eastman et al., (2011); BIWG (2011); Crotty (2012).
18	Cultural barriers to BIM implementation.	Alarcon and Conte (2003, cited in Johansen *et al.,* 2004); Cain (2003);
20, 21	External barriers affecting BIM implementation.	Emmerson (1962); Ireland (1985); Laufer and Tucker (1988); Shapira and Laufer (1993); Pearl, Bowen and Hall (1997); Ballard (2000a); Anumba, Baugh and Khalfan, (2002); Cain (2003); Winch and Kelsey (2005); Koskela, Howell and Lichtig (2006); Johansen and Wilson (2006); Raisbeck, Millie and Maher (2010); Lahdenperä (2012).
22	Internal factors affecting BIM implementation.	Li, Lu and Huang (2009); Sacks, *et al*., (2010); Owen, *et al*., (2010); Hjelseth (2010); Emmitt and Ruikar (2013).
23	BIM benefits	Wang (2002); Waly and Thabet (2003); Huang et al., (2007; 2009); Li *et al*., (2008); Rekola *et al*., (2010); Sebastian (2011); Eastman *et al*., (2011); Crotty (2012); Succar, Sher and Williams (2012); Davies and Harty, (2013a); Hartmann and Vossebeld (2013); Poirier *et al*., (2015).
27	Use of Virtual Construction (*informed by literature around the diffusion and adoption of new practice*)	Arditi and Koseoglu (1983); Mattilda and Abraham (1998); Rogers (2003).
28	Functions of Virtual Construction.	Laufer and Tucker (1987); Laufer, Howell and Rosenfeld, 1992); Howell, Laufer and Ballard (1993); Shapira and Laufer (1993); Faniran, Oluwoye and Lenard (1994); Koskela (1999); Tommelein, Riley and Howell (1999); Heesom and Mahdjoubi (2004); Johansen and Wilson (2006); Zwikael (2009).

29	Functions of Virtual Construction Environment.	Koskela (1999); Tommelein, Riley and Howell (1999); North and Winch (2002); Heesom and Mahdjoubi (2002; 2004); Chau, Anson and Zhang (2003); Winch and North (2006); Dawood, *et al*., (2002); Kenley, and Seppänen, (2010).
31	4D Planning vs. traditional planning (functions of planning).	Cullen and Nankervis (1985); Touran (1986); Laufer and Tucker (1987); Laufer *et al.,* (1994); Morros (1997); Tommelein, Riley and Howell (1999); Winch and Kelsey (2005); Winch (2010); Baldwin and Bordolo (2014).
32	4D Planning vs. traditional planning (process of planning).	Cullen and Nankervis (1985); Laufer and Tucker (1987); Laufer *et al*., (1994); Gidado (1996); Williams, (1999); Hinze (2008); Cooke and Williams (2009); Winch (2010)

E-3. Research Instrument 3: Questionnaire - Investigating the diffusion of 4D BIM innovation

This research instrument was designed to more fully address **Research Objective 4** by investigating the diffusion of 4D BIM innovation within UK construction planning practice. Specifically, 4 of its 5 sub-objectives were addressed, by exploring and explaining the: (4.1) '*construction planning functions that 4D BIM is principally being used for*'; (4.2) '*extent of use of 4D BIM innovation*' [both partially covered with Research Instrument 2]; (4.3) '*innovativeness of members of the construction social system*', and the; (4.4) '*rate of adoption of 4D BIM innovation*'.

Table E-3: Theoretical underpinning of key questions in Research Instrument 3.

NR.	Question theme	Relevant literature.
1-10	Demographic type questions.	Rogers (2003) for questions 3 and 4 (*levels of education and household income*).
11	BIM maturity level of organisation.	Eastman et al., (2011); BIWG (2011); HM Government (2011); Crotty (2012).
12-18	Perceived attributes of 4D BIM innovation	Rogers (2003)
19-30	Relative advantages of 4D BIM against functions of construction planning.	Laufer and Tucker (1987); Laufer, Howell and Rosenfeld, 1992); Howell, Laufer and Ballard (1993); Shapira and Laufer (1993); Faniran, Oluwoye and Lenard (1994); Koskela (1999); Tommelein, Riley and Howell (1999); North and Winch (2002); Rogers (2003); Heesom and Mahdjoubi (2002: 2004); Chau, Anson and Zhang (2003); Winch and North (2006); Dawood, *et al*., (2002); Johansen and Wilson (2006); Zwikael (2009); Kenley, and Seppänen, (2010).
31-37	Relative advantages of 4D BIM against stages of the construction planning process.	Cullen and Nankervis (1985); Laufer and Tucker (1987); Laufer et al., (1994); Gidado (1996); Williams, (1999); Hinze (2008); Cooke and Williams (2009); Winch (2010); Rogers (2003); Cooke and Williams (2012)
38-43	Issues of compatibility, complexity, trialability and observability	Rogers (2003)
44-46	Innovation-decision types	Rogers (2003)
47, 48	Communication Channels.	Rogers (2003); Larsen (2005a: 2005b); Larsen and Ballal (2005); Larsen (2011).

E-4. Research Instrument 4: Semi-Structured Interview Guide

This research instrument was designed to also address some of the sub-objectives of **Research Objective 4**, by obtaining further explanations about the: (4.3) '*innovativeness of members of the construction social system*', and the; (4.4) '*rate of adoption of 4D BIM innovation*'. It also helped addressed sub-objective 4.5 '*explore and explain the consequences of 4D BIM innovation*'. Furthermore, this research instrument contributed toward **Research Objective 5** helping inform model development, and making a contribution to innovation diffusion theory.

Table E-3: Theoretical underpinning of key questions in Research Instrument 3.

NR.	Question theme	Relevant literature.
1	Innovation levels in construction.	Slaughter (1988); Koskela and Vrijhoef (2001); Gambatese and Hallowell (2011a and 2011b); Demian and Walters (2014).
2	Industry structure.	Dubois and Gadde (2002); Winch (2003); Taylor and Levitt (2004a and 2004b); Harty (2005); Emmitt (2010).
3	Implementation of innovation.	Winch (1998: 2003); Harty (2005; 2008);
4	Impact of BIM upon the quality of production information.	Eastman *et al.,* (2011); Crotty (2012).
5	Impact of BIM upon planning of construction work.	Hartmann and Fischer (2007) Eastman *et al.,* (2011); Crotty (2012).
6	4D BIM innovation decision process	Emmitt (1997); Rogers (2003)
7	Communication channels	Rogers (2003); Kale and Arditi (2010).
8	Key actors in innovation diffusion	Emmitt (1997); Rogers (2003); Larsen (2005a: 2005b); Larsen and Ballal (2005); Larsen (2011).

9	Consequences of innovation adoption/rejection.	Rogers (2003)
10	Time predictability	-

Glossary

1D	1 Dimensional
2D	2 Dimensional
3D	3 Dimensional
4D	4 Dimensional
4D-PS	4D Planning and scheduling
4DSMM	4D Site management models
AEC	The Architecture, Engineering and Construction industry
AIA	The American Institute of Architects
AOA	Activity-on-Arrow technique
AON	Activity-on-Node technique
ARCOM	Association of Researchers in Construction Management
AS	Analysability (Complexity and uncertainty factor)
BIM	Building Information Modelling
BIMM	Building Information Modelling and Management
BIS	Department for Business, Innovation and Skills[1]
BOQ	Bills of Quantities
BSF	Building schools for the future
CAD	Computer Aided Design
CAQDAS	Computer Assisted Qualitative Data Analysis Software
CCM	Critical Chain Method
CDP	Contractor Design Portion
CDE	Common Data Environment
CE	Concurrent Engineering

1 BIS was replaced by the Department for Business, Energy & Industrial Strategy (BEIS) in June 2016

CIB	International Council for Research and Innovation in Building and Construction
CIOB	Chartered Institute of Builders
CPDD	Construction planning during design
CPIC	Construction Project Information Committee
CPM	Critical Path Method
CM&E	Construction Management and Economics (Journal)
CS	Complete Specification (Complexity and uncertainty factor)
CSA	Critical Space Analysis
DCP	During-construction planning stage
DfMA	Design for manufacture and assembly
GDP	Gross Domestic Product
GPS	Global Positioning System
GUI	Graphical User Interfaces
GUID	Global Unique Identifier (Relates to BIM Objects)
GVA	Gross Value Added
HHI	Household income (as a measure of social status)
IAI	International Alliance for Interoperability
ICT	Information and Communications Technology
IDDS	Integrated Design and Delivery Solutions
IDT	Innovation Diffusion Theory
IFC	Industry Foundation Classes
IPD	Integrated Project Delivery
ICT	Information and Communication Technologies
ITT	Invitation to tender
JIT	Just In Time
KPI	Key Performance Indicator
LC	Lean Construction

LCI	Lean Construction Institute
LBMS	Location Based Management System
LPS	Last Planner System
LPDS	Lean Project Delivery System
MMC	Modern methods of construction
NBS	National Building Specification
nD	*n* Dimensional
NRM	New Rules of Measurement
OECD	Organisation for Economic Co-operation and Development
OSM	Off-site manufacture
OV	Overlapping of construction elements
PA	Project Alliancing
PBP	Pre-bid planning stage
PBS	Product Breakdown Structure
PCP	Pre-construction planning
PDM	Precedence Diagramming Method
PfS	Partnerships for Schools
PLC	Public Limited Company
PP	Project Partnering
PPC	Planned percent complete (see LPS)
PPT	People, process and technology (problems associated with)
PQQ	Pre-Qualification Questionnaire
QA	Quality Assurance
QC	Quality Control
RPCF	Research participant consent form
RIBA	Royal Institute of British Architects
RICS	Royal Institute of Chartered Surveyors
RFID	Radio Frequency Identification

RPDA	Relational Project Delivery Arrangement
RS	Rigidity of sequence
SME	Small and Medium-Sized Enterprises[2]
SMM7	The Standard Method of Measurement, 7th Edition.
SNA	Social Network Analysis
TC	Technical Complexity (Complexity and uncertainty factor)
TD	Task Difficulty (Complexity and uncertainty factor)
TFV	Transformation-flow-value generation theory of production
TGC	Traditional general contracting
TPO	Temporary Project Organisations
TOC	Theory of Constraints
TPS	Toyota Production System
TRI	Interdependences of different technologies
UKCI	U.K. Construction industry.
UF	Unfamiliarity (Complexity and uncertainty factor)
UN	Lack of uniformity of work (Complexity and uncertainty factor)
UP	Unpredictability of the environment (Complexity and uncertainty factor)
VC	Virtual Construction
VCE	Virtual Construction Environment
VDE	Virtual Design Environment
VE	Virtual Environment
VP	Virtual Prototyping
VR	Virtual Reality
WBS	Work Breakdown Structure

2 In the UK, small business of 1-49 employees and medium size business that have 50-249 employees often categorised together as SME's

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